Does Bracing Affect Bone Health in Females with Adolescent Idiopathic Scoliosis?

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Thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in Applied Health Sciences

(Kinesiology)

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Abstract

This study examined the bone mineral content (BMC) in young women with Adolescent Idiopathic Scoliosis (AIS), treated with a brace (27.9 ±21.6 months, for 18.0±5.4 h/d) during adolescence (AIS-B, *n* = 15, 25.6 ±5.8 yrs), versus women with AIS but no treatment (AIS-NB, *n* = 15, 24.0 ±4.0 yrs), and women without AIS (C, *n* = 19, 23.5 ±3.8 yrs). After controlling for lean body mass, calcium and vitamin D daily intake, and strenuous physical activity, femoral neck BMC was lower in the AIS-B compared with AIS-NB and C (all *p*'s < .05). In summary, women with AIS, braced during their growing years are characterized by low lower limb BMC. However, the lack of a relationship between brace treatment duration and BMC, suggests that bracing was not the likely mechanism.

Funding: Federal Economic Developmental Agency for Southern Ontario's Applied Research and Commercialization ("ARC") Initiative.

Acknowledgements

First, I would like to thank my supervisor, Dr. Bareket Falk, for her unconditional support from the very first day that I met her. I am sincerely honored to have had you as supervisor and mentor for the past two years. I am grateful for all your support and advice, both on an academic and personal level. You truly are the best mentor I could have ever asked for and I thank you from the bottom of my heart. I would never have come this far without your guidance and help throughout this project.

I would also like to thank my committee members, Nota Klentrou for her skills and expertise in research and bone health, and Dr. Philip Wilson for his expertise in the statistical part of the project and for always keeping my best interest in mind. Dr. Wilson, your comforting words definitely helped ease my anxiety and nervousness in the days nearing my thesis defense. I also enjoyed being in your AHSC5P00 course; you definitely have a unique way of reaching out to students. I would also like to thank Alan Rigby, without whom this project would not have been possible, and Dr. Matthew Greenway who was an essential asset when it came time to interpreting the DXA results. I would like to give a big thanks to the CML-Xray staff, particularly to Robin for prioritizing our participants and making them feel comfortable during the DXA scans. You are an amazing technologist who is excellent at her job. I would like to say a special thanks to Bev Minor for watching out for all the graduate students. You play a very important role in the life of a graduate student, which we often take for granted. I just want to thank you for everything, from your warm smiles to making sure we graduate on time.

I would also like to thank each and every participant who took part in this study. It goes without saying that this study would not have been possible without you. I would like to thank Kim Kish for making the data collection process fun and enjoyable. I miss our Timmie runs and us munching sunflower seeds while waiting for the participants to arrive. Whatever happen to our pet Gertrude? I wish you all the best in your thesis defense! I would like to thank Atena (Izzy) Ludwa, for training me on the QUS system and being my test subject over and over until I got it right. I also want to thank you for your expertise on bone health. I will miss you "lab momma"! I wish you all the best with your little bundle of joy. I would like to thank Yasmeen Mezil for being a good friend and just being there. I hope we continue our Sushi lunch breaks! I would like to thank Charmaine Kissmann for being a great friend and for coming into my life at just the right time.

A very big thank you to my parents for always being there for me and always supporting me in all of my endeavors. I am very blessed to have parents like you, and I would not be where I am today without all of your love and encouragement. Dad, I thank you very much to teaching us the value of education. You were, are and will always be an inspiration to me. I would like to thank my brothers and sisters for their endless love and support and last minute babysitting services. I am truly blessed to have such an amazing family. I would also like to thank my husband for his support and encouragement.

And finally, to my two beautiful daughters, Zala and Zoya, who made the biggest sacrifice of all, these two years I spent attaining my Masters Degree belong to you, and so I dedicate this thesis to the two of you. I hope to instill within you the same value and love for education as your grandparents instilled in me. I love you both very much!

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Abbreviations

AIS	Adolescent Idiopathic Scoliosis
AK	Adolescent Kyphosis
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
ATI	Angle of trunk inclination
ATR	Angle of trunk rotation
aBMD	Areal bone mineral density (g/cm^2)
BF%	Body fat percentage (%)
BMC	Bone mineral content (g)
BMD	Bone mineral density (g/cm^2)
BMI	Body mass index (kg/m^2)
BSI	Bone strength index
BUA	Broadband ultrasound attenuation (megahertz/ decibel)
Ca++	Calcium (mg)
CS	Congenitial Scoliosis
DXA	Dual-energy X-ray absorptiometry
FN	Femur/femoral neck
FW	Femur ward
GCs	Gait cycles
GT	Greater Trochanter
Ht.	Height (cm)
IPAQ	International physical activity questionnaire
IU	International units
Kcals	Kilo calories
LBM	Lean body mass (g)
LPAQ	Lifetime physical activity questionnaire
LS	Lumbar spine
METs	Metabolic equivalents
MSCs	Mesenchymal stem cells
PBM	Peak bone mass
pQCT	Peripheral quantitative computed tomography
QOL	Quality of life
QCT	Quantitative computed tomography
QUS	Quantitative ultrasound
RAM	Rapid assessment method
RDI	Recommended daily intake
SD	Standard deviation
SOS	Speed of sound (m/s)
TBM	Total bone bass (g)
TFM	Total fat mass (g)
TLM	Total lean mass (g)
TLSO	Thoracic lumbar-sacral orthosis
Total EI	Total energy intake (kcal)
vBMD	Volumetric bone mineral density (g/cm^2)
VOS	Velocity of sound (m/s)
Wt.	Weight (kg)

Chapter 1: Introduction

1.1 Purpose of the Study

The purpose of the study was to assess the effects of brace treatments on bone mineral content (BMC) and bone speed of sound (SOS) in adult women who were diagnosed with adolescent idiopathic scoliosis (AIS) and braced in their early adolescence. Their BMC was compared with scoliotic women of same age and ethnicity who did not receive any treatment intervention, and with non-scoliotic women of the same age and ethnicity.

1.2 Research Questions

1. Does bracing during adolescence affect bone mineral content (BMC; total body, hip, lumbar spine, proximal femur, arms and legs) during adulthood?
2. Does bracing during adolescence affect bone speed of sound (SOS; non-dominant radius and tibia) during adulthood?

1.3 Research Hypotheses

1. AIS women who had been treated with a brace will have lower bone mineral content (BMC) than the women who received no treatment and the control group.
2. AIS women who had been treated with a brace will have lower tibial and radial speed of sound (SOS) values than the women who received no treatment and the control group.

Chapter 2: Review of Literature

2.1 Scoliosis

Scoliosis is a nonspecific complex amalgamation of many diseases and is associated with a serious imbalance of mechanical stresses on the spine, its joints and ligaments (Stehbens, 2003). Scoliosis can occur in childhood and adulthood. Scoliosis occurring in adulthood usually has a known cause and is often associated with age-related changes in bone structure. Scoliosis occurring during childhood is of unknown etiology and is referred to as idiopathic scoliosis. Idiopathic scoliosis can be subdivided into three categories, depending on the age at which it is diagnosed: (1) infantile scoliosis is detected before age three, (2) juvenile scoliosis occurs in children between the ages of three and ten years and (3) adolescent scoliosis is diagnosed after age 10 and up until bone maturity at 18 to 20 years of age (James, 1954; Stehbens, 2003).

Adolescent idiopathic scoliosis (AIS) is the most common type and can be defined as a persistent lateral curvature of the spine of more than 10° in the upright or standing position. Although the lateral curvature is the main component, it can also be associated with rotation of the spine and various plane curvatures. These additional curvatures and rotation make AIS a complex three-dimensional deformity (Park, Suh, Kim, Kim & Lee, 2009). The etiology and pathogenesis of idiopathic scoliosis remain unknown. The consensus is that the etiology is multifactorial (Li, Li, Liu & Dai, 2008).

2.2 Prevalence of AIS

The prevalence of scoliosis can vary from study to study due to the variation in age, sex and bone maturation, diagnostic cut points, severity criteria and duration of follow-up (Lonstein, 2006). AIS is prevalent in 2-4% of children from 10 to 16 years of age (Lonstein, 2006). Stirling and his coauthors (1996) studied almost 16,000 children aged 6-14 years in England and found a prevalence of AIS (Cobb angle >10°) to be 0.5%. The prevalence of scoliosis was highest (1.2%) in participants aged 12-14 years (Stirling, et al., 1996). When smaller Cobb angles are used (e.g., 6° or greater), a significantly higher scoliotic rate may be identified, such as the 4.5% prevalence reported by Rogala, Drummond and Gurr (1978). In a study by Willner and Uden (1982), scoliosis was found in 1.2% of boys and 4.3% of girls. The study found that the greater the curvature (i.e. greater than 20 degrees), the higher the proportion of females compared to males with AIS. Furthermore, curves in females increase or progress more aggressively than in males. The same study also found that girls with AIS were significantly more likely than boys to have a family history of scoliosis (Willner & Uden, 1982).

2.3 Assessing AIS

AIS, is usually painless. The initial indication of the condition is usually the observation of prominence of the back (Bunnell, 1985), particularly during the Adam's Forward Bend Test. The Adam's Forward Bend Test is the most common diagnostic procedure used as the first stage of screening for AIS (Greiner, 2002). Once AIS is suspected, the Cobb angle is measured using the traditional standing posteroanterior radiograph of the full spine. The most tilted vertebral bodies above and below the apex of

the spinal curve are used to create intersecting lines that give the curve degree, known as the Cobb angle (Figure 1) (Greiner, 2002). Curves are named for the location of the apex vertebrae, and may be described as thoracic, lumbar, thoracolumbar, cervical, or double major (two curves in different spinal regions), and are labeled as "right" or "left" curve depending on the curve convexity (Greiner, 2002; Negrini et al., 2010). The prominence, or rib hump noted in the forward bending test, can also be quantitatively measured with a scoliometer. Scoliometer is an inclinometer designed to measure trunk asymmetry or the angle of trunk inclination (ATI), sometimes called the angle of trunk rotation (ATR). It is recommended to measure the ATR at three levels of the spine, corresponding to the location of structural curves: proximal thoracic, main thoracic, thoracolumbar or lumbar. This method is simple, inexpensive and non-invasive and can provide objective measurements that can effectively determine whether further orthopedic evaluation is needed (Negrini et al., 2010).

Source: Reamy, 2001

Figure 2.1. The Cobb method
Measuring the degree of scoliosis. The angle between intersecting lines drawn perpendicular to the top of the superior most tiled vertebrae and the bottom of the inferior most tilted vertebrae is the Cobb angle (here, 62 degrees) (Reamy, 2001).

2.4 Treatment options

Treatment of adolescent idiopathic scoliosis depends on the size (Cobb's angle) and location of the curve and the growth remaining for the patient. In general, patients with curves between 0 and 20 degrees are observed for progression. These patients are assessed periodically, using radiography, to note any curve progression. For curves >20°, there are two accepted modes of treatment in AIS: surgery and bracing (Negrini et al., 2010). Often, these treatment modes are accompanied by therapeutic exercise (Weiss et al., 2006). Surgery, aimed at curve correction and maintenance, is usually recommended for curves greater > 40° in skeletally immature adolescents (Weinstein, Dolan, Cheng, Danielsson & Morcuende, 2008). In a 2008 systemic review, Weis and Goodall concluded that surgical procedures do not meet their main aim. That is, neither back shape nor self-esteem was corrected to a satisfactory level by the surgical procedure. Their estimated long-term risk of re-operation was > 30%.

For individuals with curves of 20° to 40°, a brace (or orthosis) is used if progression is documented and the individual has substantial growth remaining (Maruyama, Grivas & Kaspiris, 2011). Bracing is considered a conservative treatment as opposed to surgery. The primary aim of bracing is not to correct the curve but to prevent further curve progression during the growing years, in the hopes of avoiding surgery (Maruyama et al., 2011). Brace treatment attempts to mechanically modify the scoliotic spine shape and control progression of the spinal curvatures by applying pressure to specific pressure points on the torso.

Although there are questions regarding its effectiveness, bracing is currently used as a standard non-operative treatment of AIS. There are many different types of braces

developed for use in patients with AIS; some of the earlier and most commonly used braces include the: Milwaukee Brace, Boston Brace, Cheneau Brace, Providence Brace and the Charleston-Night Time Brace (Sponseller, 2011). The first widely used scoliosis brace with proven effectiveness was the Milwaukee Brace, which is classified as a "rigid module" (Moe & Kettleson, 1970; Wong & Liu, 2003). Lonstein and Winter (1994) studied 1,020 patients with AIS who were treated with the Milwaukee Brace and reported that this orthosis was effective in preventing curve progression in patients with 20-39 degree curves. Thoracic lumbar-sacral orthosis (TLSO) braces, such as the Boston, Charleston and Cheneau Braces, are not as rigid as the Milwaukee Brace (Weiss & Rigo, 2011). Nachemson and Peterson, (1995), showed that bracing alters the natural history of adolescent idiopathic scoliosis in the short term (4 years), but its efficacy in the long term has remained controversial. Recent studies suggest that the efficacy of bracing, in terms of reduction of curve progression and the number of patients, who eventually undergo surgery, is good in compliant patients (Rahman, Bowen, Takemitsu & Scott, 2005; Seifert, Selle, Flieger & Gunther, 2009), where compliant patients are defined as those who wear the brace > 20 hours daily (Brox, Lange, Gunderson, & Steen, 2012; Rahman et al., 2005). Thus, the weak evidence of the effectiveness of bracing may partly be explained by poor compliance.

2.5 Brace Compliance

There is still controversy surrounding the amount of time a brace should be worn on a daily basis. Compliant patients who wore the brace for more than 18 hours per day had less curve progression than those who wore it 12 hours or less per day Banta (Wiley,

Thomson, Mitchell, Smith & Banta, 2000). For braces to be effective, they should be worn for 16-23 hours per day (Liljenqvist, Witt, Bullmann, Steinbeck & Volker, 2006; Nachemson & Peterson, 1995). Therefore, the effectiveness of bracing seems to be dependent on patient compliance and continuous wearing of the brace on a regular basis (Helfenstein et al., 2006). Generally, compliance with prescribed brace-wear regimens has been shown to be poor. On average AIS participants wear their brace 65% of the prescribed amount of time. Patients who are prescribed part-time bracing (16 hours per day) actually demonstrated worse compliance (58%) than those prescribed full-time bracing (71%). Overall, only 15% of patients demonstrated a highly compliant (≥ 90%) brace-wear routine (DiRaimondo & Green, 1988). Reasons for non-adherence are numerous and include wearing discomfort, cosmetic aspects of the rigid and bulky brace and, in particular, the fear of reduced trunk muscle usage and restrictions in everyday physical activities (Muller et al., 2011) that can potentially affect the patient's overall quality of life (QOL) (Bunnell,1985).

2.6 Quality of life

The condition itself may result in social problems, and brace treatments can further negatively contribute towards self and body image, interactions with others and overall QOL (Bunnell, 1985). The severity of AIS, skeletal maturity, duration of brace treatments and degree of corrections are all clinical factors that can affect QOL (Climent & Sanchez, 1999). Furthermore, AIS patients experience higher stress levels when asked about their brace, as opposed to their deformities, indicative of the difficulties AIS

patients experience when subjected to conservative treatments (Climent & Sanchez, 1999).

Although bracing has been shown to have favorable outcomes when a patient is complaint (Weiss, 2003), because bracing is considered a traumatic experience with the potential of leaving emotional scars (Dickson & Weinstein, 1999; Saccomani, Vercellino, Rizzo & Becchetti, 1998), the psychological stress associated with wearing a brace often outweighs any perceived benefits. MacLean, Green Pierre & Ray (MacLean, Green, Pierre & Ray, 1989) studied 31 adolescent and preadolescent females undergoing part-time brace treatment for their AIS. They found that 84% of their patients described the initial period of bracing in "stressful terms" and experienced lower levels of self-esteem.

2.7 How does Bracing Limit Physical Activity?

The main purpose of brace treatment for scoliosis is to prevent spinal curve progression. The impact of spinal bracing on physical activity has been poorly described in the literature and remains inconclusive. From a clinical perspective, in order for a rigid brace to be effective, it must control posture, stabilize body motion, and immobilize the trunk in order to prevent the progression of the curve (Rogala et al., 1978). However, in doing so the brace limits the use of core muscles and limits everyday physical activity (Climent, J.M., 1999). It is known that low bone density and fractures may be a consequence of immobilization and muscle weakness (Li et al., 2008). Immobilization of the forearm after hand or wrist surgery significantly decreases bone mass in the distal radius and ulna (Houde et al., 1995). Therefore, it has been postulated that bracing for

adolescent scoliosis could result in permanent loss of bone mineral; a predisposition to adult osteoporosis (Li et al., 2008).

Muller et al. (2010) assessed the impact of wearing the Cheneau Brace on physical activity patterns in daily life in two patients with scoliosis. The results showed increased levels of physical activity in one participant and decreased level of physical activity in the other participant. In another study by Muller et al. (2011), a controlled study was conducted to objectify the impact of spinal bracing on daily step activity in patients receiving brace treatment (AIS) or adolescent kyphosis (AK). Step activity (using a pedometer-based uniaxial accelerometer) was assessed without braces for seven consecutive days. After 8 weeks of brace wearing, step activity was assessed during regular brace treatment, again for seven consecutive days. They reported that although step activity decreased in AIS patients between the pretreatment and follow-up measurements from 5,069 ± 1,453 to 4,988 ± 1,528 gait cycles (GCs)/day and increased from 397 ± 106 to 403 ± 137 GCs/hr, the differences were not statistically significant. During the follow-up measurements, AIS patients had slightly, but not significantly, reduced movement intensities at 14.3 ± 2.8 GCs/min when wearing the brace in comparison with 14.7 ± 4.3 GCs/min at times when the brace was discarded. They concluded that although brace treatment had no impact on habitual activities, the overall mean step activity before and during brace treatment, was lower in AIS and AK patients in comparison with the expected values for healthy peers in other studies.

Danielsson, Romberg and Nachemson (2006) investigated the long-term outcome in terms of spinal mobility and muscle strength in patients who were braced or surgically treated, and concluded that spinal mobility and muscle endurance were reduced, even 20

years after the treatment completed. There seems to be mixed evidence regarding the effects of bracing on physical activity and function. Further studies are warranted to examine the effects of bracing and physical activity in the scoliosis population.

2.8 The Effects of Exercise on Bone

During growth bone increases substantially in mass and in length. The final shape achieved by a mature bone is a result from continuous modeling and process affected by genetics, dietary, hormonal and physical factors (Biewener, Swartz and Bertram, 1986).

Mechanical forces also have a major influence on the bone modeling and remodeling processes in both cortical and trabecular bone. One of the proposed mechanisms by which mechanical forces affect bone strength is captured by Frost's "mechanostat" theory (Figure 2.2), which illustrates the mechanical stimulus of bone to strain "set-points" resulting from different loading environments into four distinct zones (Frost 1987).

1. Trivial loading zone, which is characterized by strain magnitudes smaller than 200με and so no mechanical stimulus to bone occurs.
2. Physiological loading zone (200–2000με), bone remodeling is maintained at a steady state, which preserves bone strength.
3. Bone modeling is stimulated in the overload zone (2000–3000με), and therefore new bone is added.
4. Bone suffers micro-damage and woven bone is added in the pathological overload zone, when strain magnitude in response to mechanical loading

exceeds 4000με (Frost, 1987; Al Nazer, Lanovaz, Kawalilak, Johnston, & Kontulainen, 2012).

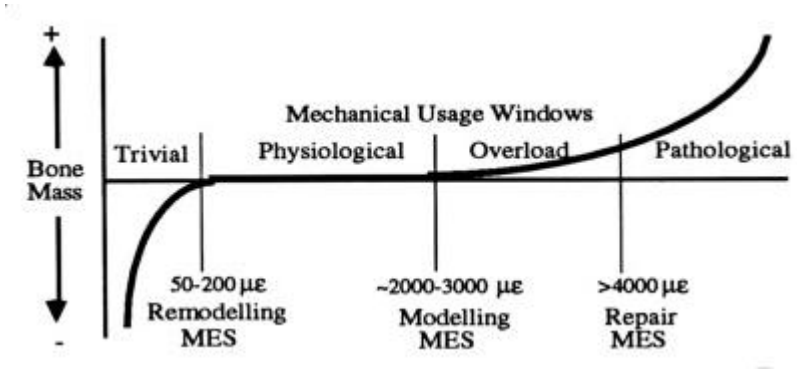

Figure 2.2: Mechanostat theory relating strain magnitudes to bone response (Al Nazer et. al., 2012).

These mechanical "set-points" are not constant but vary not only from person to person (Frost, 1994), but also from site to site (Ruff, 2006; Skerry, 2006). Age, genetics, drugs, hormones, disease can change the "set-point" and as a result the changes can affect the bone architecture.

A comparison between in vivo strains values in different bones during similar exercise were investigated by in a systematic literature review by Al Nazer et al. (2012). According to the results from several in vivo strain measurements studies, the calcaneus was exposed to significantly higher principal strains during barefoot walking compared to the medial tibia and proximal lateral femur (5500με, 395με and 1198με, respectively). According to the mechanostat theory, this suggests that barefoot walking will expose the calcaneus to higher risk of stress fracture while the same activity will maintain bone strength at the medial tibia and proximal lateral femur since the strain produced within

these two sites are within the physiological loading zone (Al Nazer et. al., 2012). In summary then, there is not one mechanostat in each of our skeletons but many of them (Skerry 2006).

Studies have revealed that the osteocytes respond to mechanical stimulation (Klein-Nulend et al., 1995). It is postulated that mechanically induced osteocyte (derived from osteoblasts) signals are transferred to the surface of the bone where they control osteoclast and osteoblast activity (Burger & Klein-Nulend, 1999). Therefore, when physical activity is performed, the muscles involved in the activity pull on the bone (mechanical stimulation) and create a strain. In order for bone formation to occur, the strain resulting from the mechanical stimulation needs to exceed the set-point threshold of the bone. Exceeding the threshold is dependent on the intensity at which the activity is performed. The higher the intensity of the activity, the greater the strain, that is produced on the bone (Frost, 1987).

Physical activity plays an important role in maximizing bone mass during early childhood and the early adult years. The benefits of physical activity on bone health have typically been assessed by measuring association of physical activity level with bone mass and incidence of fractures, or by evaluating changes in bone mass that occur in response to a change in physical activity level or to a specific exercise training program. There is considerable evidence from epidemiologic studies that physical inactivity is a risk factor for hip fracture in adults. The incidence of hip fracture has been found to be 20–40% lower in individuals who report being physically active than in those who report being sedentary (Gregg, Pereira & Caspersen, 2000).

Studies have suggested that to improve bone accretion, the mode, intensity and duration of the exercise should be considered, and for optimal bone mineral accrual these activities should be performed before or in the early pubertal period (Kohrt et al., 2004). Similarly, in a meta-analysis MacKelvie, Khan, & McKay (2002) concluded that bone is most responsive to exercise, such as weight-bearing and high impact exercise, during the very early stages of puberty.

In a cross-sectional study, Bass (2000) investigated the relation between maturity and bone mineral in 91 female racquet sport players aged 7–17 and reported that areal bone mineral density (aBMD) of proximal humerus, humeral shaft, and distal radius were significantly greater in players than controls at Tanner stages 3, 4, and 5, with no differences between Tanner stage 1 players and controls. In a longitudinal study Bailey and his colleagues reported ~26% of final adult bone mineral status is accrued in the 2 adolescent years surrounding peak BMC velocity (Bailey, McKay, Mirwald, Crocker & Faulkner, 1999). Similarly, Slemenda and his co-authors report a bone mineral accumulation of 30% of adult BMC over 3 peripubertal years as determined by Tanner staging (Slemenda, Miller, Hui, Reister & Johnston, 1994). Thus, it seems that as much bone mineral is being laid down during the adolescent years as most people will lose during their entire adult lives (Bailey, 1997).

It has been observed that bone mass is higher in children who are physically active than in those who are less active (Slemenda et al., 1991), and higher in children who participate in activities that generate high impact forces (e.g., gymnastics and ballet) than in those who engage in activities that involve lower impact forces (e.g., walking) or are not weight bearing (e.g.,swimming) (Courteix et al., 1998).

In a longitudinal study, Bailey and his colleagues (1999) investigate the influence of physical activity on bone mineral accrual during the adolescent years. They analyzed 6 years of data from 53 girls and 60 boys. They noted a 9% and 17% greater total bone BMC for active boys and girls, respectively, over their inactive peers one year after the age of peak BMC Velocity. In an interventional study by Morris, Naughton, Gibbs, Carlson and Wark (1997), bone mineral, strength and lean mass response to a 10-month, high-impact, strength-building exercise program in 71 premenarcheal girls, aged 9–10 years was explored. Their results showed after the 10 month intervention, the exercise group gained significantly more BMD/BMC, greater shoulder, knee and grip strength and more lean mass, and less body fat content. Although much of the bone mineral accrual in the premenarcheal skeleton was related to growth, an osteogenic effect was associated with exercise, thus making the premenarcheal years appears to be an opportune time to gain benefits from exercise. The results of their study suggest that by increasing the magnitude of the mechanical loading on the bone through increased lean mass and engaging in high-impact exercise, it was possible to stimulate a greater increase in bone mineral accrual (Morris et al., 1997).

In another longitudinal study, the authors investigated whether children who participated in a 7-month targeted, impact exercise intervention exhibited skeletal benefits 7 years after the intervention had ceased. The impact exercise consisted of jumping intervention (100 jumps off a 24-in box 3 times/wk). BMC was assessed by DXA at baseline, 7 and 19 mo after intervention, and annually thereafter for 5 yr. They noted that, after the 7 months intervention, those children that completed high-impact jumping exercises had 3.6% more BMC at the hip than control subjects whom completed

nonimpact stretching activities ($p < .05$) and 1.4% more BMC at the hip after nearly 8 yr (BMC adjusted for change in age, height, weight, and physical activity; $p < .05$) (Gunter et al., 2008). They propose that if the benefits of such impact exercises are sustained into young adulthood, effectively increasing peak bone mass, fracture risk in the later years could be reduced. However, whether these benefits persist into adulthood and contribute to the development of peak bone mass is unclear.

2.9 Overview of Bone

Bone is a complex, highly organized and specialized connective tissue. It is characterized physically by the fact that it is a tissue that is hard, rigid and strong (Bailey, Faulkner & McKay, 1996). Bone tissue is mineralized into two basic forms: cortical (compact) bone and trabecular (cancellous) bone (Bailey et al., 1996). The cortical bone is the densely compacted tissue that forms the outer surface of all bone and accounts for about 75-80% of the total skeletal mass (Bailey et al., 1996). Trabecular bone is the spongy, porous type of bone found at the ends of all long bones and within flat and irregular bones, such as the sternum, pelvis, and spine, and accounts for approximately 20-25 % of the total skeletal mass (Bailey et al., 1996).

Bone undergoes longitudinal and radial growth, modeling and remodeling during life. Longitudinal and radial growth occurs during childhood and adolescence. Longitudinal growth occurs at the growth plates, where cartilage proliferates in the epiphyseal and metaphyseal areas of long bones, before subsequently undergoing mineralization and being replaced by primary new bone (Kobayashi et al., 2003). Modeling is the process by which bones change their overall shape in response to

physiologic influences or mechanical forces, leading to gradual adjustment of the skeleton to the forces that it encounters. Bones may widen or change axis by removal or addition of bone matrix to the appropriate surfaces by independent action of osteoblasts and osteoclasts in response to biomechanical forces (Kobayashi et al., 2003). Bone remodeling is the process by which bone is renewed to maintain bone strength and mineral homeostasis. Bone is remodeled continuously through the resorption of old bone by resorptive cells, the osteoclasts, and the subsequent formation of new bone by formative cells, the osteoblasts (Manolagas, 2000). These two closely coupled events are responsible for renewing the skeleton, while maintaining its anatomical and structural integrity (Manolagas, 2000), and ultimately determining bone strength (Schoenau & Frost, 2002). Under normal conditions, bone remodeling proceeds in cycles in which osteoclasts adhere to bone and subsequently remove it by acidification and proteolytic digestion (Clarke, 2008). Shortly after the osteoclasts have left the resorption site, osteoblasts invade the area and begin the process of forming new bone by secreting osteoid , a matrix of collagen and other proteins, which is eventually mineralized (Manolagas, 2000).

Bone mass accounts for 50 to 70% of bone strength (Pocock et al., 1987). Bone mineral provides mechanical rigidity and load-bearing strength to bone. Bone mineral content (BMC) can be defined as the absolute amount of mineral present in a bone or regions of a bone, and bone mineral density (BMD) as the amount of bone mineral per measured or volume of bone (Bailey et al., 1996). BMC provides quantitative information regarding skeletal development, whereas BMD provides a more qualitative assessment, while attempting to control for size differences (Bailey et al., 1996) Peak

bone mass is the maximal lifetime amount of bone tissue that is accrued in the skeleton during growth (Ott, 1991). At least 90% of the adult BMC is deposited by the end of adolescence (Matkovic et al., 1994). The most rapid period of skeletal development occurs over several years in childhood and adolescence, accounting for 40–50% of the total accrual of skeletal mass (Bonjour, Theintz, Buchs, Slosman & Rizzoli, 1991; Slemenda et al., 1994). The period between 9 and 20 years of age is critical for attaining an optimum peak bone mass (Matkovic, Ilich & Hsieh, 1993). Thus, this period may provide the best opportunity to maximize peak bone mass. This is of particular importance in AIS patients, who have been shown to have low BMD (Cheng et al., 2000; Cheng, Sher, Guo, Hung & Cheung, 2001); Lee, et al., 2005; Park et al., 2009; Sadat-Ali, Al-Othman, Bubshait & Al-Dakheel, 2008; Szalay, et al., 2008; Thomas et al., 1992; Zhu, Qiu, Yeung, Lee & Cheng, 2009). Many are treated with braces within this critical period of bone mineralization (Lonstein, 2006). Therefore, as suggested by Schoenau & Fricke (2008), since the braces are rigid and restrict movement of the spine, and possibly limit physical activity in general; peak bone accretion may be hindered, thus putting them at an increased risk for osteoporosis and bone fractures later in life.

2.10 Bone Assessment

Bone densitometry technology has advanced during the past two decades, and is now commonly used in clinical practices for monitoring osteoporosis and in studies that use bone density as the surrogate marker of bone health rather than using the endpoint of bone fracture (Bonnick, 2002; Small, 2005). Bone density testing consists of two types: central and peripheral. Since osteoporotic fractures typically occur in bones composed of

a high proportion of trabecular bone, such as the vertebral body, the proximal femur and the distal radius, these sites are commonly chosen for the measurement of BMD and are considered as central testing (Duboeuf, Pommet, Meunier & Delmas, 1994) using technology such as Quantitative computed temography (QCT) and Dual energy X-ray absorptiomety (DXA). Peripheral testing measures bone density at other anatomical sites such as heel, finger, forearm, kneecap or shin using technology Quantitative ultrasound (QUS). It is used when central testing is not available, but is not effective for diagnosing or monitoring treatment of osteoporosis (Lenchik et al., 2002, Cook et al., 2005).

2.10.1 Dual Energy X-Ray Absorptiometry (DXA)

Introduced in 1987, dual-energy x-ray absorptiometry is used to assess specific skeletal sites as well a whole body BMC and BMD (Fogelman & Blake, 2000). For the use of assessing risk of osteoporotic fractures, DXA-derived BMC values are usually examined at the lumbar spine, proximal femur and distal radius. DXA is widely used because of its good reproducibility and accuracy, its low radiation dose, its capability of measuring bone density at both axial and appendicular skeletal sites, its ease of use, short scan times, and stable calibration (Bonnick, 2002; Fogelman & Blake, 2000; Fogelman & Blake, 2005; Small, 2005). One of the limitations of DXA is that the measurement is two-dimensional and therefore, BMD is expressed as aBMD), in g/cm^2. These measurements therefore tend to underestimate BMD in small individuals (Duboeuf et al., 1994). Another limitation of DXA is that there is poor agreement between models due to use of different algorithms by different companies and sometimes within the same companies but different models (Shepherd et al., 2006). DXA has a precision error of ~0.5-3.0% (Pocock et al., 1997).

2.10.2 Quantitative Computed Tomography (QCT)

Other methods of assessing risk for osteoporosis include Quantitative Computed Tomography (QCT) measurement. Since aBMD as measured by DXA is size-dependent, this can be a particular problem if patients are small in size and in growing children (Duboeuf et al., 1994). QCT measures true volumetric bone mineral density (vBDM) (Engelke & Gluer, 2006), and so is not size-dependent. QCT can be more sensitive to change in BMD, compared with DXA-aBMD (Levis & Altman, 1998). QCT provides geometric and structural parameters of bones which contribute to skeletal strength. Bone strength measurements include moments of inertia and stress-strain indices which both correlate well to the fracture load and can be calculated with the geometric and structural parameters provided by QCT. Trabecular bone can be eight times more metabolically active than cortical bone. QCT allows separate measures of BMD of the trabecular, and cortical bone compartments, providing for a better understanding of the effects of disease/treatment upon bone (Riggs et al., 2008). One of the limitations of QCT is the relatively high ionizing radiation involved in scanning central sites (spine and hip) than those of DXA. Another limitation is that there are fewer published reference data for QCT than for DXA, with particular paucity in men and children (Adams, 2009). Finally QCT is not as widely available as DXA, and is more expensive.

2.10.3 Quantitative Ultrasound (QUS)

Quantitative Ultrasound (QUS) has been proposed as an alternative method for assessing bone health. (Williams, Wilson, Biassoni, Suri, & Fewtrell, 2012). QUS is the only established technique for non-invasive assessment of bone status that does not require radiation. QUS techniques are safe, easy to use, relatively inexpensive and free

from radiation. (Baroncelli, 2008; Binkley, Berry & Specker, 2008) . There are two types of QUS systems which can be separated on the basis of their measurement technique: transverse and transaxial. Transverse techniques systems are the most widely used techniques and are based on assessment of the transmission of ultrasound waves *through* the skeletal site being measured, with measurement of speed of sound (SOS in meters per second) and broadband ultrasound attenuation (BUA in megahertz per decibel) (Njeh, Boivin & Langton, 1997). The most frequently measured sites are the calcaneus, where the trabecular component is dominant (Baroncelli, 2008; Williams et al., 2012). When the speed of sound is measured, the greater the connectivity of the trabeculae, the faster the sound waves will go through the bone (Levis & Altman 1998). In transaxial, SOS is measured *along* the cortical bone of the tibia, radius and even the phalanges. Sunlight Omnisense: Sunlight Medical Ltd., Tel-Aviv, Israel is one of the commonly used QUS systems, used to assess cortical SOS in the long bones.

Currently, ultrasound can be used to discriminate between normal and osteoporotic women, and could be considered an alternative to DXA in the baseline screening and evaluation of fracture risk, but not to diagnose osteoporosis or to target treatment (Lenchik, et al., 2002; Cook, Collins, Tucker & Zioupos, 2005). Bone density testing results are usually reported as T-scores and Z-scores. Clinical decisions are based on the T-score, which is calculated by comparing the patient's BMD with the mean value for young normal adult and expressing the difference as a standard deviation score. According to Bonnick (2002), The T-score is calculated using the formula:

$$\textbf{T-score} = \frac{\textbf{Patient's BMD} * \textbf{Young Normal Mean}}{\textbf{SD of Young Normal}}$$

In addition to the T-scores, DXA reports also provide Z-scores, which are calculated similarly to the T-score, except the patient's BMD is compared with an age-matched (and race- and gender-matched) mean, and the result expressed as a standard deviation score (Aoki, et al., 2000). A low Z-score indicates that bone density is lower than expected and should trigger a search for an underlying cause (Bonnick, 2002). Low bone density is defined as bone density measured at or between 1 and 2.5 standard deviations below the mean BMD of young normal adult; osteoporosis is defined as bone density measured at 2.5 standard deviations or more below the mean BMD of young normal adult (Aoki et al., 2000). For each standard deviation decrease in bone density, estimated fracture risk increases by 10% (Small, 2005).

2.11 Bone in AIS

There is a growing concern that adolescents with idiopathic scoliosis may have a lower peak bone mass, thereby increasing the risk of developing osteoporosis and related complications in later life (Cheng et al., 2000), especially in women (Jones, et al., 1994). Osteoporosis is a disease characterized by low bone mass and deterioration of bone tissue, which can lead to increased bone fragility and risk of fracture, particularly of the hip, spine and wrist. It is one of the most common metabolic bone disorders that increase in prevalence in older populations (Saggese, Baroncelli & Bertelloni, 2001). Normally, osteoporosis is not common in adolescents. However, adolescents with AIS are at a higher risk for developing osteoporosis because they have lower BMD than adolescents without AIS (Thomas et al., 1992). Table 2.1 summarizes studies that have examined BMD values in girls with AIS. According to Cheng, Guo and Sher (1999), 27-38 % of

people with AIS also have low BMC. Lee et al. (2005) observed that bone mass of 596 girls (aged 11 to 16 years) with AIS was on average 6.5 % lower than the control group of 302 girls. Lam et al. (2011) studied girls of the same age category using DXA and QUS. The crude comparison showed that BUA, velocity of sound (VOS or SOS) and stiffness index (SI) of AIS group were 3.8% , 0.5% and 6.9% ($p < .01$) lower than controls, respectively, even after controlling for confounding factors (maturity, body weight, height, and BMD). Another study looked at female siblings, one with scoliosis and the other without scoliosis, and found that of the 32 AIS girls 29 had low bone mass, while their siblings with normal spine curvature had normal BMD (Sadat-Ali et al., 2008). A similar trend in BMD values was noted in another study by Cheng, et al., (2001) who reported that in 75 AIS girls, 38% of the aBMD and 36% of the vBMD were below 1 SD of the norm. They also noted that over 86% of osteopenic AIS patients had persistently low BMD, at both distal tibia and femoral neck regions, at the time of skeletal maturity. The results from these studies are in conflict with a recent study by Szalay et al. (2008), who found that 87% of AIS had normal BMD and only 12% had low BMD. There seems to be a general consensus among the different studies that females of different ethnicities with AIS, all seem to exhibit overall lower BMD compared to normal healthy females of the same age and ethnicity.

Studies examining the relationship between the Cobb's angle and BMD have reported an inverse relationship between AIS severity and BMD values; higher Cobb's angle was associated with lower BMD levels (Cheng et al., 2000; Lee et al., 2005). The authors suggested that scoliosis-related osteopenia weakens the spinal architecture and may contribute to the progression of the curvature during growth. Other studies show no

significant relationships between the degree of Cobb's angle and BMI (Snyder et al., 1995; Snyder, Katz, Myers, Breitenbach & Emans, 2005; Thomas et al., 1992).

Table 2.1: Studies examining bone mineral status in AIS

Authors	AIS (n)	Control (n)	Age (years)	Ethnicity	Study Design	Outcome variable	Main Findings
Thomas et al., 1992	22	Na	11-20	Caucasians and blacks	Follow up 30.8 months	DXA BMD: LS, FN,WT,GT	Generalized osteopenia 55-60 % of the BMD values for LS and FN were below the 95% CI for normal expected values.
Snyder et al., 1995	43 (Braced)	42 (Obs)	14 ±3	NA	Cross sectional	BMD using DXA (FN, LS)	Mean annual change in BMD in AIS girls was [0.062 g/cm^2 (LS) and 0.043g/cm^2 (FN)], was lower at the LS and similar at the FN compared to that of healthy girls of same age (norm) from a different study [0.08g/cm^2 and 0.004 g/m^2 (FN)]
Cheng et al., 2000	75	94	12-14	Chinese	Cross sectional	-DXA: aBMD-(L2-L4, proximal femur) -pQCT: vBMD(non-dominant distal radius, bilateral distal tibias) -Cobbs's angle	In the AIS girls ,36- 38 % had low aBMD and vBMD
Lee et al., 2005	596	302	11-16	Chinese	Cross sectional	DXA: aBMD of FN and LS pQCT: vBMD of radius and tibia Ca intake and PA	Bone mass of AIS was on average 6.5% lower than controls ($P<0.05$). Calcium intake and PA were significantly correlated with bone mass of AIS

Qiu et al., 2008	49	NA	10-16	Female	Pre/ post bracing: 1 year	DXA: BMD & BMC (LS and FN)	Mean annual change in BMD in AIS girls was [0.054 g/cm^2 (LS) and 0.076 g/cm^2 (FN)], was lower at the LS and slightly higher at the FN compared to that of healthy girls of same age (norm) from a different study [0.08g/cm^2 and ,04 g/m^2 (FN)]
Sadat-Ali et al., 2008	32	27 (Sisters)	14-26	Arabian	Comparative Study	DXA: t- and z-scores, BMD and BMC of proximal femur, lumbar spine	Hip BMD: 62.5 % of AIS were osteoporotic, 28.1% were osteopenic Spine BMD: 29/32 of AIS girls had low bone mass, in comparison to the scoliotic girls, girls with normal spine had a normal BMD p<0.001.
Szalay et. al., 2008	49	40	11-20	NA (males and females	Case control	DXA: z-scores aBMD of : Spine, hips, femur z-scores	12% of AIS and 2.5 % of controls had low BMD
Park et. al., 2009	19	6 (leg fracture)	11-14	NA Females and male	Cross sectional	Osteogenic differentiation abilities and alkaline phosphatase activities of MSCs DXA : BMD (LS, FN)	Mean LS BMD in AIS was lower than in controls(p=0.0037) MSC activity and osteogenic differentiation abilities in AIS were lower than in control (p=0.0073 and p=0.001 respectively). Suggest that decreased osteogenic differentiation ability of MSCs might be one of the possible mechanisms leading to low bone mass in AIS

Zhu et al., 2009	15 (AIS) 16 (CS)	35	12-19	Chinese	Cross sectional	DXA: BMD/BMC (FN, L2-4 spine) Biopsy and micro CT of the iliac crest	Low bone mineral status and weak trabecular bone structure in AIS and congenital scoliosis (CS)
Lam et al., 2011	635	629	11-16	Chinese	Case Control	DXA:z-scores BMD of FN QUS: BUA,VOS,SI (non-dominant calcaneus)	FN BMD was significantly Lower in AIS. - BUA, VOS, and SI of AIS group were 3.8% ($P < 0.01$), 0.5% ($P = 0.042$), and 6.9% ($P < 0.01$) lower than controls, respectively. -After controlling confounding factors, BUA and SI were significantly lower in AIS ($P < 0.05$) for both mild and moderate Cobb's angle

Abbreviations:

AIS: Adolescent Idiopathic Scoliosis
aBMD: Areal bone mineral density (g/cm^2)
BMC: Bone mineral content (g)
BMD: Bone mineral density (g/cm^2)
BSI: Bone strength index
BUA: Broadband ultrasound attenuation(megahertz/ decibel)
CS: Congenital Scoliosis
CT: computed tomography
DXA: Dual-energy X-ray absorptiometry
FN: Femur/femoral neck
FW: Femur ward
GT: Greater trochanter
LS: Lumbar spine
MSCs: Mesenchymal stem *cells*
PBM: Peak bone mass
Obs: Observed
pQCT: Peripheral quantitative computed tomography
QUS: Quantitative ultrasound
SOS: Speed of sound (m/s)
vBMD: Volumetric bone mineral density (g/cm^2)
VOS: Velocity of sound (m/s)
WT: Ward's triangle

2.12 Bone and Physical Activity in AIS

There are only a handful of studies that have examined the suitability of physical activity for AIS. The majority of the studies have all discussed the importance of physical activity and encouraged the patients to participate in structured and un-structured physical activity with and without brace treatment (Liljenqvist et al., 2006; Danielsson et al., 2006). Recently, some attention has been given to the impact of bracing on physical activity and its effects on BMD in AIS patients. To be effective, it is recommended that a brace be worn at least 23 hours a day (Liljenqvist et al., 2006; Nachemson & Peterson, 1995), but due to the discomfort associated with wearing the brace, the levels of physical activity can be limited in patients who are braced. Lee et al. (2005) suggested that, the widely accepted practice of bracing for the treatment of mild to moderate curves during the second decades of life may come at the price of reduced physical activity in the braced AIS patients, which could exacerbate their lower bone mass. Other studies found that brace treatments did not interfere with bone density accumulation during adolescence. Of the studies that examined the effects of bracing on bone (Table 2.2), only a few studies reported levels of assessed physical activity, via self-reports from which they concluded, no differences between the AIS braced group and control groups (Snyder et al., 1995; Snyder et al., 2005; Courtois, Collet, Mouilleseaux &Alexandre, 1999).

2.13 The Effects of Bracing on BMD

Bracing for AIS has been postulated to result in permanent loss of bone mineral mass and predispose adults to early onset of osteoporosis (Li et al., 2008). There are

limited studies which have looked into the effects of bracing on BMD. These are summarized in Table 2.2.

One of the early studies that attempted to look at values of BMD in AIS girls before and after bracing was by Thomas et al. (1992). In this study, the researchers conducted a follow-up study on participants from a previous study that looked at BMD values in AIS girls of mixed ethnicity and mixed treatment interventions. Their results showed lower BMD values in AIS participants compared to control group healthy girls and from initial observation to follow-up of 28.5 month to 41 months, a decrease in BMD values was noted at the proximal femur, an increase in BMD at the LS and FN (Thomas et al., 1992). The major limitation of this study was that, of the 22 AIS participants, only 3 were actually braced. Due to the small sample of braced AIS girls, the power is insufficient to confirm the trends noted in their study. Another major limitation is the fact that the results presented reflect those of Caucasians and Blacks with different treatment interventions. They did not look at the BMD values of the 3 braced girls separately. Thus, conclusions drawn from this study do not capture the actual effects of bracing on AIS patients.

In a 1995 study, Snyder and his colleagues conducted a cross-sectional comparison of BMD in AIS girls who were braced with girls who had AIS but were only observed. The study showed that BMD at the spine and hip were similar for both groups of girls, even after controlling for curve severity and type, activity and diet. They suggested that since the study was cross-sectional in design, the values noted for the BMD were only a "snap shot" of the BMD at that particular time, and did not reflect the actual effects of brace wear on bone density accumulation with growth and development

(Snyder et al., 1995). To address the limitation in their first study, years later Snyder et al. (2005) conducted a longitudinal study that examined the effects of bracing after 1 year of wear in girls with AIS. The conclusion was that bracing did not affect BMD significantly at the spine and hip even after 1 year of bracing. In fact, 96% of their participants had a significantly positive annual rate of change in BMD at the hip and spine (Snyder et al., 2005). One of the main limitations to this study is that the follow-up was only after one year. This short duration of brace wear is likely insufficient to capture the changes occurring in bone. Another limitation to this study was that despite it being a longitudinal study, the researchers were unable to objectively measure actual brace wear, and so again the changes in BMD noted may not reflect the true effects of bracing on bone density during adolescence. As well, there was no control group consisting of age-matched and curve severity matched AIS patients who were observed only. The inclusion of such a control group would make the findings more conclusive.

In 2006, Sun, Qiu and Zezhang, investigated the accumulation of BMC and BMD in braced AIS adolescent patients in a follow up study to determine if bracing had an adverse effect on bone health. The results of their study showed that after 1 year of brace treatment AIS patients presented with increased FN (95.0 %) and LS BMC (87.5%). They also showed that during bracing FN and LS BMC increased at a rate of 0.61 g/yr and 4.88 g/yr, respectively. They did not find any significant correlation between average daily brace wear time and the annual rates of change in BMC (Sun, Qiu, & Zhu, 2006). In a more recent study by the same authors, similar results were reported (Qiu et al., 2008). They also concluded that initial bone mineral status may not be a major player in BMC accumulation and that “growth potential” of AIS is the main factor influencing bone

mineral accrual during brace treatment (Qiu et al., 2008). The above two studies were both very similar in their results and limitations. A major limitation was that there was no control group, consisting of age-matched and curve severity-matched AIS patients who did not wear a brace. Without such a control group the conclusion is unclear since BMC and BMD are expected to increase with growth in all AIS girls.

In 1999, Courtois et al., studied BMD at the femur and lumbar spine in a population of young women treated for scoliosis with a brace in adolescence and compared them to age-matched healthy women. This is the only study to our knowledge that has examined the long term effects of bracing in female AIS. The study showed lower mean BMD values for the scoliosis groups at the femur and lumbar sites, although statistical significance was observed only at the lumbar sites (Courtois et al., 1999). The major limitation of this study is that it is a cross-sectional study and a cause-effect relationship cannot be concluded. Another limitation to their study was that they failed to account for dietary intake and physical activity at the time of bracing or in adulthood. These factors play a major role in bone remodeling, especially at a very critical period during which peak bone mass is attained. Another limitation is that they failed to examine the effects of bracing or scoliosis on the peripheral skeleton. Furthermore, the study did not mention the ethnicity, nor did they account for body composition of the participants.

Table 2. 2: Data from studies on the effects of bracing on bone mineral status in female AIS

Authors	AIS-B (n)	C (n)	Age (years)	Ethnicity	Study Design	Outcome Variable	Findings
Thomas et al., 1992	22	Na	11-20	-Whites -Blacks	Follow up (30.8 months)	DXA:BMD (LS, FN,WT,GT)	Decrease in proximal femur BMD and increase in BMD at the LS and FN. Limitation: Only 3 patients were actually braced. They did not look at the braced group separately.
Snyder et al., 1995	43	42 (Obs)	14 ±3	NA	Cross sectional	BMD using DXA (hip, spine)	No difference in BMD between groups.
Courtois et al., 1999	33	33 (Healthy)	Pre:13.2 ±1.5 Post:30.5±6	NA	Longitudinal 2-25 yrs	Pre: NA Post: DXA-BMD femur and lumbar	Lower mean BMD values for the scoliosis groups at the femur and lumbar sites, with only L2, L3 and L2-4 attaining statistical significance of p= 0.01, 0.01, and 0.05, respectively. The main limitation to their study was that they failed to account for dietary intake and physical activity and the ethnicity of the participants.

Snyder et al., 2005	52	NA	13.6 ±1.5	Females (NA)	Longitudinal 1 year follow up	BMD using DXA (hip, spine)	In AIS annual rate of BMD accumulation was 0.062 g/cm^2 and 0.043 g/cm^{2}at the LS and at the FN, respectively compared to the 0.08 g/cm^2 (FN) and 0.040 g/cm^2 (LS) noted in normal healthy girls.
Sun, Qiu & Zhu, 2006	40	Na	10.2-16.6	Females (?)	Longitudinal (followed at a 3-4 month interval up 1 year)	BMD using DXA (hip, spine)	Increase in BMD and BMC in FN and LS over 1 year of brace treatment. Comments: there was no control groups consisting of age matched and curve severity matched AIS patients.
Qiu et al., 2008	49	NA	10-16	Female	Pre/ post bracing: 1 year	DXA: BMD/ BMC (LS and FN)	>94% of AIS girls had accumulation of BMD and BMC values at both sites after 1.1 years of brace treatment

Abbreviations:

AIS: Adolescent Idiopathic Scoliosis
AIS-B: Adolescent Idiopathic Scoliosis with brace treatment
aBMD: Areal bone mineral density (g/cm^2)
BMC: Bone mineral content (g)
BMD: Bone mineral density (g/cm^2)
C: Control
DXA: Dual-energy X-ray absorptiometry
FN: Femur/femoral neck
GT: Greater trochanter
LS: Lumbar spine
MSCs: Mesenchymal stem *cells*
PBM: Peak bone mass
Obs: Observed
pQCT: Peripheral quantitative computed tomography
QUS: Quantitative ultrasound
SOS: Speed of sound (m/s)
vBMD: Volumetric bone mineral density (g/cm^2)
VOS: Velocity of sound (m/s)
WT: Ward's triangle

To date the studies that have attempted to examine the effects of bracing on bone density (Table 2.2) are inconclusive for the following reasons:

1. The average follow-up period in these studies was a little over 1 year; the longest follow-up was in the study by Thomas et al. (1992) in which there were only 3 braced AIS participants. There are no follow-up studies to date that have examined the effects of bracing into adulthood with larger sample sizes. Braces are usually recommended until skeletal maturity occurs, so to test the effects of bracing, studies should follow-up into adulthood.
2. In most of the studies there were no measures of actual brace wear and compliance was self-reported. It can be very difficult, if not impossible, to verify patient compliance in any long-term follow-up studies.
3. Most of the participants in the above studies are of Chinese descent. Genetics account for 78%, 76% and 79% of the variance in BMD measured at the lumbar spine, femoral neck and total body, respectively (Nguyen, Howard, Kelly & Eisman, 1998). Furthermore, persons of African-American lineage demonstrate higher BMD while those of Chinese lineage demonstrate lower BMD compared with Caucasians (Bachrach et al., 1999). Therefore, we cannot generalize such finding to Caucasians or the general population.
4. It should be pointed out that all studies examined skeletal sites characterized by trabecular bone whereas no study examined peripheral sites, characterized mainly by compact bone.

Chapter 3: Research Methods

3.1 Study Design

This research study is a non-experimental, cross-sectional design that compares bone BMC and SOS in women who had been diagnosed with AIS and braced in their adolescence with that of women who had been diagnosed with AIS but did not receive any treatment, as well as with that of healthy women with no AIS. Bone mineral content was assessed using DXA and bone SOS was assessed by QUS.

3.2 Participants

All participants were female, aged 18-39 years, of Caucasian decent. The study is comprised of three groups:

a) Women who were diagnosed with AIS and braced during early adolescence (n = 15).

b) Women who were diagnosed with AIS but did not receive any treatment interventions (n = 15).

c) A comparison group of age-matched women without AIS and no history of bracing (n = 20).

AIS women were recruited through posters, digital and social media and word of mouth. Participants for the age-matched control group were recruited from a purposive sample from Brock University and local cities. The exclusion criteria were: a) males, b) use of tobacco or alcohol on a regular basis, c) medical conditions that affect bone health (eg. nutrient malabsorption, hypothyroidism, diabetes, lactose intolerance, hypogonadisim, hyperpituitarism, renal failure, malnutrition, rickets, scurvy) d) bone fractures, and e) pregnancy.

3.4 Protocol

All participants were tested in a single visit at the CML Health Care clinic. All participants were required to wear lightweight clothes (yoga pants and t-shirt), and remove any jewelry including, hair clips, belly-button rings, earrings etc. Upon arrival, the participants were informed of the details of the study and tests involved. Subsequently, an informed consent form (Appendix 2.3) and screening questionnaire (Appendix 2.4) were completed. DXA scans were then performed assessing spine, hip and whole body BMC, BMC as well as body composition. Once DXA scans were completed QUS was performed to determine bone SOS at the distal one third of the non-dominant radius, and mid-shaft of the non-dominant tibia. Additionally, participants completed questionnaires assessing medical history, scoliosis history, nutritional and current and past physical activity (Appendices 2.5 to 2.10).

3.5 Methods

3.5.1 Questionnaires

All participants completed a screening questionnaire on previous X-rays, pregnancy, surgeries, chemotherapy, bone fractures, medical conditions, medications, family history of osteoporosis, extreme diets and age at menarche (see Appendix 2.4). Background scoliosis-related information was attained using a separate questionnaire (appendix 2.5) (e.g., age of diagnosis, age of bracing, type of brace and Cobb angle and compliance).

The 24-hour Nutritional Recall Questionnaire (Appendix 2.10) was administered as an interview to assess nutrient intake on recent a typical day. This questionnaire is a

good estimate of total energy, calcium and vitamin D intake in adolescent females (Greger and Etnyer, 1978). Data obtained from this questionnaire was analyzed by a single investigator, using Axxya System's Nutritionist Pro Diet Analysis (Stafford, TX, USA) to quantify total energy intake, calcium and vitamin D intake.

Physical activity (workplace, household and structured activity) over the course of their life-time was assessed using the international physical activity questionnaire (IPAQ) (Appendix 2.8) (Friedenreich, Courneya, & Bryant, 1998). Current physical activity was measured using the Godin-Shephard leisure-time exercise questionnaire (Godin & Shephard, 1985) (Appendix 2.6), which assessed the number of times on average the participant performed mild, moderate and vigorous exercise, for more than 15 minutes a day during their free time within a 7-day period.

All questionnaires, except for the 24-Hour recall questionnaire, were completed by the participant in the presence of an investigator in order to clarify or answer any questions the participant might have had.

3.5.2 Anthropometric Measurements

Anthropometric measurements included height and body mass. Height was measured by a free standing stadiometer (model: SECO) to the nearest 0.1 cm, with the mandible plane parallel to the floor. Body mass was measured in kg to the nearest 100 grams, in light gym clothes without shoes on a commercial electronic scale (model: EKS). Body mass index (BMI) was then calculated by dividing weight (kg) by height squared (m^2). Percent body fat and lean mass were obtained using DXA.

A scoliometer was used to assess the degree of curvature in braced and non braced AIS females only. Scoliometers have been used as an assessment tool of the

curvature in the initial stages. All measurements using the scoliometer were obtained by the same investigator.

3.5.3 Bone Measurements

Bone mineral content of the total body, hip and spine, were measured using a GE Lunar Prodigy DXA bone densitometer at the CML X-ray center in St. Catharines. A single operator performed all DXA scans to eliminate inter-observer variability. Anterio-posterior (AP) scans were obtained. The hip and spine scans were obtained with the participants positioned supine on the densitometer table, with hips and knees flexed at 90°, to minimize lumbar lordosis. Whole body scans were obtained with the participants lying supine, with the legs internally rotated. Rays from DXA scanners pass through the body, and a cumulative attenuation is measured. Therefore, in the DXA bone region, the measured attenuation represents a combination of all soft tissue and bone in the path of the beams. The attenuation values are used to generate a 2D projection image and to calculate areal BMD (aBMD, g/cm^2), BMC (g), and body composition.

The QUS measurements were performed by a single investigator using Sunlight Medical Ltd.'s Sunlight Omnisense™ model 7000P (Tel Aviv, Israel). This device consists of a main unit and a hand-held probe. The probe, which contains a set of two transmitters and two receivers, housed in a compact holder is designed to measure bone SOS at specific skeletal sites on the non-dominant extremity. The non-dominant extremity, theoretically may have received less loading and thus the SOS should be less than or equal to the dominant side. The non-dominant limb was determined by asking the participants which leg they use to kick a ball and which arm they use for writing. Bone SOS at the distal 1/3 of the non-dominant radius, and mid-shaft of the non-dominant tibia

was measured using a tape measure. The 1/3 radial measurement site was determined as the midpoint between the olecranon process and the tip of the third phalanx. The mid-shaft tibia was determined by measuring half-way between calcaneus and the top of the knee while the subject was seated with the knee and ankle at 90° angle. To measure radial SOS, wide scans of 140 degrees around the radius were performed. To measure tibial SOS, scans from the tibial crest to the medial end were performed. All measurements consist of at least three consistent cycles. At the start of each day of testing, the probe and system were checked by undertaking a system quality verification procedure against a standard acrylic phantom. Results are expressed in m/sec. The same operator performed all measurements in order to minimize operator and technical variability.

There were no discomforts reported by any participants during the measurements outlined in this study. Measurement and questionnaires required approximately 90 minutes per participant. All participants recruited completed all parts of the study successfully. Coefficients of variations for 10 adults, tested twice within the same day were calculated for DXA and QUS in order to determine the reliability of the measurements and are presented in Table 3.1.

3.6 Statistical Analysis

All data were entered into an Excel spreadsheet by a single investigator. Data was approximately normally distributed according to the normal distribution criteria by Tabachnick and Fidell (2013). In the AIS-braced group, AIS-Not braced group and Control groups, 5.8 %, 7.7%, 11.5 % of the data's skewness was > | 2.00| and 3.8%, 5.8%, 7.7% of the data's kurtosis was > |7.00|, with 3.8%, 5.8%, 7.7% of data being

both skewed and kurtotic, respectively. The skewness and kurtosis for each variable are presented in appendices 3.17 to 3.22 by groups. The differences in BMC and SOS between the control group, AIS with brace and AIS without treatment were tested using a one way Analysis of Variance (ANOVA). ANOVAs were also used to assess the difference between groups in nutritional intake, physical activity and physical characteristics. Bivariate covariates were examined using the Pearson correlation coefficients (r). For the Analysis of Covariance (ANCOVA), the following variables were entered as covariates in examining group differences in bone characteristics: Past and current physical activity, calcium and vitamin D intake and lean body mass. Covariates were determined using physiological approach. That is, variables that have been shown through previous literature to have an effect on our main outcomes variables (BMC and SOS) were used as covariates, regardless of the corresponding Pearson correlation coefficients. Thus, covariates included variables of body size (lean body mass), nutritional intake (vitamin D and calcium) and physical activity (past and present). Chi-square test was used to examine differences between groups in background medical information (e.g., past fractures, regularity of menses). In order to examine possible differences between groups in the regional distribution of bone mineral, a ratio was calculated between BMC at peripheral (eg. legs BMC) vs. axial (L1-L4) skeletal sites. Statistical analyses were performed using SAS Ver. 16.0. Data are presented as means ± SD. Statistical significance was set at $p < .05$ (2-tailed).

Table 3.1: Coefficient of Variation for QUS and DXA measurement

Variables	CV(%)
Radial SOS	0.4
Tibial SOS	0.5
Whole body Total Fat	1.9
Whole body total BMC	2.0
Left arm BMC	3.5
Left leg BMC	2.0
Left side BMC	8.0
Trochanter BMC	3.4
Femur neck BMC	2.9
Ward BMC	7.3
Total Hip BMC	5.9
L1 BMC	2.0
L2 BMC	1.8
L3 BMC	4.7
L4 BMC	3.3
Total spine BMC	4.6

Chapter 4: Results

4.1 Sample

A total of 52 females with and without scoliosis between the ages of 19 and 44 replied to the recruitment advertisements placed in bulletin boards, local newspapers and websites from March 2012 to March 2013. Of these 52 females: 20 were healthy females without scoliosis or conditions that affect bone health and constituted the 'control' group (C), 17 were females who had adolescent Idiopathic Scoliosis and treated with a brace during their early adolescents and constituted the 'braced' group (AIS-B), and 15 were females who had AIS but did not receive any treatment and constituted the "not-braced" group (AIS-NB). From the healthy controls, one female was excluded from data analysis because she did not meet the age criteria (39.8 yrs at time of testing). In the scoliosis braced group, 2 females were excluded. One was excluded due to her ethnicity (Black), and another female due to her age (44 yrs at time of testing). The final sample consisted of 19 for the control group, 15 for the braced group and 15 for the not-braced group (Figure 4.1).

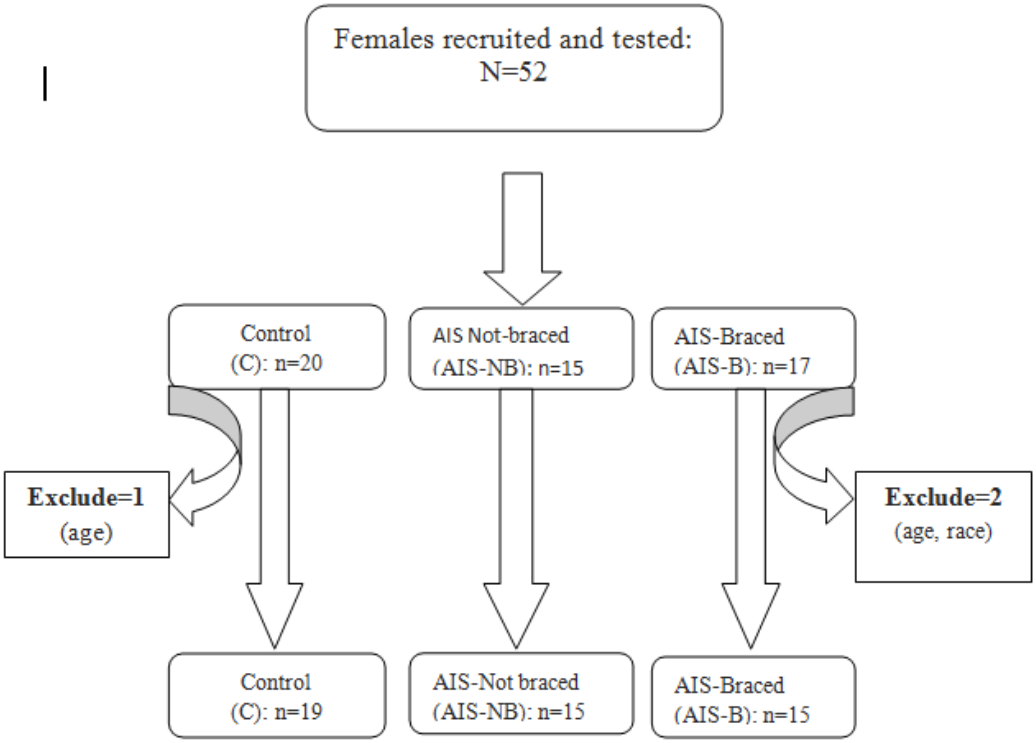

Figure 4.1: Sample selection process for data analysis

4.2 Personal and Medical Background

Chi-square analysis for personal and medical background data for each group is presented in Table 4.1. Overall, there were no significant differences between the groups in any of the variables.

Table 4.1: Personal and medical background information for the braced, not-braced and control groups presented as total cases per group and Chi-square

	Brace (*n* = 15)	**Not-Braced (*n* = 15)**	**Control (*n* = 19)**	χ^2
Past fractures	3	7	4	3.47
Family history/osteoporosis	2	1	0	2.60
Past extreme diets	0	2	1	2.40
Past mal-absorption	2	0	0	4.73
Past chemotherapy	0	1	0	2.31
Past irregular menes	1	3	1	2.28
Past/current tobacco Use	3	1	1	2.28
Past /current alcohol use	2	3	3	0.25
Past/current birth control	9	8	8	1.12
Past/current medical conditions	Ulcerative colitis, Hyperthyroidism	Hypothyroidism	NA	2.60

Note: Values are presented as total number of cases per group, there were no significant differences between groups ($\chi^2 < 5.99$)

4.3 Physical Characteristics

The physical characteristics of the participants in each group are presented in table 4.2. There were no significant differences in age, height, body mass, BMI, % body fat, total bone mass, total lean mass or age of menarche between the three groups.

Table 4.2: Physical characteristics of the braced, not-braced and control group presented as means ±SD

	Brace (*n* = 15)	**Not-Braced (*n* = 15)**	**Control (*n* = 19)**	**ANOVA**
Age (yrs)	25.6 ±5.8	24.0 ±4.0	23.5 ±3.8	.41
Height (cm)	167.3 ±7.9	167.1 ±7.2	167.3 ±5.7	.99
Weight (kg)	63.1 ±13.2	64.54 ±10.2	65.2 ±9.0	.85
BMI (kg/m^2)	22.4 ±3.3	23.09 ±3.3	23.2 ±2.6	.71
Body fat %	30.41 ±6.8	30.8 ±8.5	33.3 ±7.6	.48
Total bone mass (g)	2543.2 ±522.5	2662.7 ±502.1	2655.3 ±323.8	.71
Total fat mass (g)	18748.0 ±8234.0	19144.8 ±8023.7	20810.2 ±6892.5	.70
Total lean mass (g)	41089.0 ±5722.3	41619.1 ±5521.8	40565.2±4396.1	.84
Age of menarche (yrs)	13.1 ±1.7	13.0 ±2.0	13.9 ±1.4	.95

Note: Values are presented as means ± SD; there were no significant differences between groups ($p > 0.05$).

4.4 Nutritional Intake

The dietary information regarding daily values of total energy, calcium (Ca^{++}) and dietary vitamin D intake for each group is presented in table 4.3. There were no significant differences between the braced, not-braced and control group total energy intake (Kcals), calcium or dietary vitamin D intake. All groups had mean calcium intakes that were above the recommended daily intake (DRI) of 1000 mg for ages 19-55 years (Health Canada, 2012). However, 53% of the participants in each group had daily Ca^{++}

intake below the DRI. Daily Ca^{++} intake ranged from 372.4 to 2774.0 mg, 267.7 to 3459.2 mg and 250.3 to 2346.7mg for AIS-B, AIS-NB and the C groups, respectively All groups had dietary vitamin D intakes that were 25% to 32% of the recommended daily vitamin D intake of 600 IU for ages 9 to 70 years (Health Canada, 2012). Vitamin D intake ranged from 12.5 to 466.41 (IU) for the AIS-B group, 13.6-1042.3 (IU) for the AIS-NB group (only one participant met the DRI) and 9.2 -240.18 (IU) for group C.

There was no significant difference for supplemental calcium and vitamin D intake between the 3 groups as measured by questionnaire. In the braced group two participants took both calcium and vitamin D supplements for the past 18 months; while another participant had just recently started taking vitamin D supplement. In the non-braced group there were 3 participants who took both calcium and vitamin D supplements while 4 others took either vitamin D or calcium supplement. The duration of supplement intake ranged from recently to up to 6 six years. In the control group only 1 participant took both calcium and vitamin D supplement while 3 others took either or within the last year. The main source for the above supplements was women's multivitamins.

Table 4.3: Daily Nutritional intake for the braced, not-braced and control groups

	Brace (*n* = 15)	**Not-Braced (*n* = 15)**	**Control (*n* = 19)**	**ANOVA**
Total Energy Intake (kcal)	1832 ±960	2357±1186	1898 ±668	.23
Calcium Intake (mg)	1084 ±638	1169 ±863.4	1086 ±622	.93
Dietary Vitamin D (IU)	181 ±146	194 ±269.2	150 ±150	.78

Note: Values are presented as means ± SD; there were no significant differences between groups ($p > .05$).

4.4 Physical Activity

There were no significant differences between the braced, not-braced and control group in the reported current and past physical activity (Table 4.4). Specifically, current physical activity showed no significant differences between the groups, although the braced group tended to have engaged in less mild and moderate exercise per day. Past physical activity displayed no significant differences at any of the physical activity intensities between the three groups. The braced group had consistently lower levels intensity 2, 3 and 4 physical activity (hrs/wk) compared to the not-braced and control groups, although the difference was not significant.

Table 4.4: Current and past physical activity for the braced, not-braced and control groups

		Brace (*n* = 15)	**Not-Braced (*n* = 15)**	**Control (*n* = 19)**	**ANOVA**
Current Physical Activity (times/day)	Mild	2.6 ±1.7	3.2 ±2.6	4.6 ±3.6	.10
	Moderate	2.1 ±2.0	3.0 ±2.1	3.3 ±2.5	.29
	Strenuous	2.0 ±1.9	1.9 ±1.9	2.9±1.8	.23
Past Physical Activity (hrs/wk)	Intensity 1	0.1 ±0.3	0.6 ±1.5	0.1 ±0.1	.18
	Intensity 2	1.1 ±1.7	1.2 ±3.1	1.0 ±1.5	.96
	Intensity 3	1.5 ± 1.6	3.3 ±2.7	2.9 ±4.8	.33
	Intensity 4	3.8 ±5.2	6.0 ±5.9	5.3 ±5.8	.57

Values are presented as means ± SD; there were no significant differences between groups ($p > .05$).
Mild=minimal effort (ie. easy walking), moderate=not exhausting (ie. fast walking), strenuous=heart beats rapidly (ie. running),
Intensity defined as:
1 = jobs that require only sitting with minimal walking;
2 = jobs that require a minimal amount of physical effort such as standing and slow walking with no increase in heart rate and no perspiration;
3 = jobs that require carrying light loads (5-10 lb or 2-5kg), continuous walking, mainly indoor activity and that would increase the heart rate slightly and cause light perspiration;
4 = jobs that require carrying heavy loads (>10 lb or >5 kg), brisk walking, climbing, mainly outdoor activity, that increase the heart rate substantially and cause heavy sweating.

4.5 DXA Results

The BMC values measured by DXA for the different axial and peripheral regions of the body are presented in Table 4.5 for each of the groups. The AIS-B group was characterized by lower BMC in the lower extremities, although this difference was statistically significant only at the femoral neck axis ($p = 0.03$). Once covariates were included in the analysis, these differences in BMC between groups became statistically significant (see also Figure 4.2) at the femur neck and femur wards. No group differences were observed in the upper extremities or spine. Appendix 3.1 provides the BMC values as means, SD, and values for ANOVA and ANCOVA at all measured skeletal sites for the three groups. BMD values demonstrated a similar pattern to the BMC results. However, between-group differences were not statistically significant (Appendix 3.2).

Table 4.5: BMC values per skeletal site using DXA for each group

	Brace (n=15)	**Not-Braced (n=15)**	**Control (n=19)**	**ANOVA**	**ANCOVA**
Arms	314.7 ± 74.6	324.4 ±53.6	314.8 ±33.20	0.85	0.84
Legs	911.4± 174.1	968.9±195.2	963.7 ±134.93	0.58	0.12
Pelvis	314.5 ±75.7	347.4 ±98.7	352.2 ±64.58	0.36	0.16
Femur neck axis	2.1 ± 0.3[a]	2.3 ±0.3	2.4 ±0.34[a]	0.03 *	0.01**
Femur neck	4.5 ±0.1[a]	4.9 ±0.6	5.1 ±0.58[a]	0.06	0.02**
Femur shaft	16.4 ±2.0	16.9 ±1.8	17.5 ±1.96	0.24	0.05
Ward's triangle	2.1 ± 0.5[a]	2.4 ±0.5	2.5 ±0.51[a]	0.11	.033**
Spine-L1-L4	67.3 ±13.0	67.5 ±12.0	67.5 ±10.23	0.99	0.546
Total body	2543.2 ±522.5	2662.7 ±502.1	2655.3 ±323.82	0.71	0.270

Note: Values are presented as means ± SD; A = group effect; * = ANOVA ($p \leq .05$)
** = ANCOVA: Covariates included total body lean mass, Ca^{++}, Vit. D, Intensity 4 and strenuous exercise ($p \leq .05$)

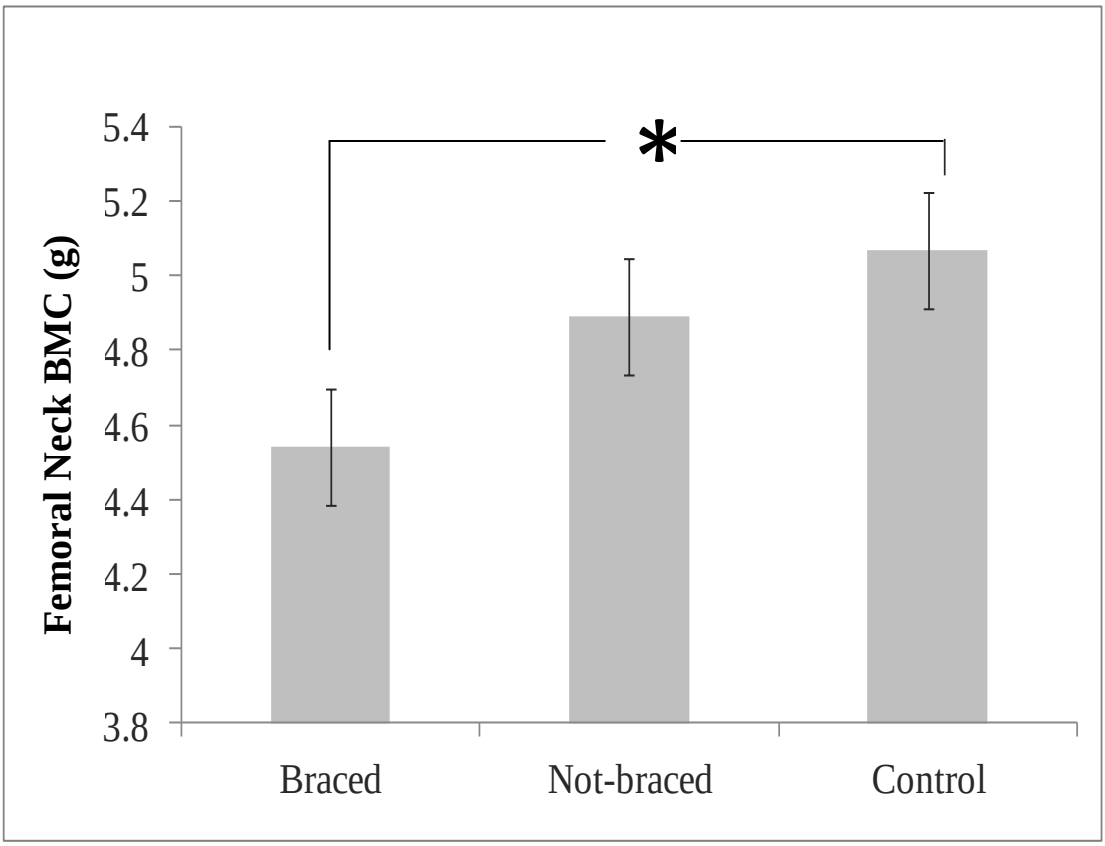

Figure 4.2: Adjusted Femoral neck BMC after controlling for total body lean mass, Ca^{++}, Vit. D, Intensity 4 and strenuous exercise (mean ±SD; *p < .01).

Pearson correlation coefficients (r) between BMC at various skeletal sites with measures of physical activity, nutritional intake and lean body mass are presented in Table 4.6. Overall, LBM was correlated with BMC at all skeletal sites. Daily calcium and total energy intake were not correlated with BMC, but vitamin D intake was. There was no significant correlation between physical activity (current or lifetime) and BMC at the various sites. When examined in the three groups separately, the pattern was similar; LBM, total energy intake and vitamin D intake were correlated with BMC whereas daily calcium intake and physical activity (current or lifetime) were not. Correlation matrices

between BMC at the various skeletal sites, physical activity indices, nutritional intake and anthropometric measures are in appendices 3.3 to 3.14.

Table 4.6: Pearson correlations (r) between BMC and measures of physical activity, nutrition and lean body mass

	Strenuous Physical Activity		Nutritional Parameters			Physical Characteristics
	Current	Past	E I	Vit. D	Ca++	LBM
Arms	0.17	0.03	-0.02	0.32*	0.23	0.71**
Legs	0.14	0.15	0.05	0.34*	0.25	0.72**
Pelvis	0.18	0.08	0.09	0.30*	0.12	0.56**
Femur neck axis	0.26	0.27	0.12	0.17	-0.07	0.46**
Femur neck	0.22	0.17	0.01	0.14	-0.03	0.53**
Femur shaft	0.26	0.22	0.13	0.30*	0.14	0.58**
Femur wards	0.13	0.16	-0.03	0.10	-0.20	0.50**
Total Femur	0.23	0.18	0.10	0.30*	0.10	0.61**
Spine (L1-L4)	0.13	0.07	0.16	0.37*	0.14	0.68**
Total Body	0.12	0.05	0.01	0.31*	0.20	0.60**

Note: EI= Energy intake, Vit. D = Vitamin D, Ca++ = Calcium, LBM=Lean body mass o
**Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

Scatter plots were performed to look at the association between femur neck BMC and reported brace wear. There were no significant associations between femur neck BMC and brace wear in the total number of months (Figure. 4.3) or hours/day (Figure 4.4), r^2= 8E-05 and r^2=0.02, respectively. Similarly no associations were noted between the measured angle of curvature using a scoliometer and femoral neck BMC in any of the groups (Appendix 3.23 to 3.25)

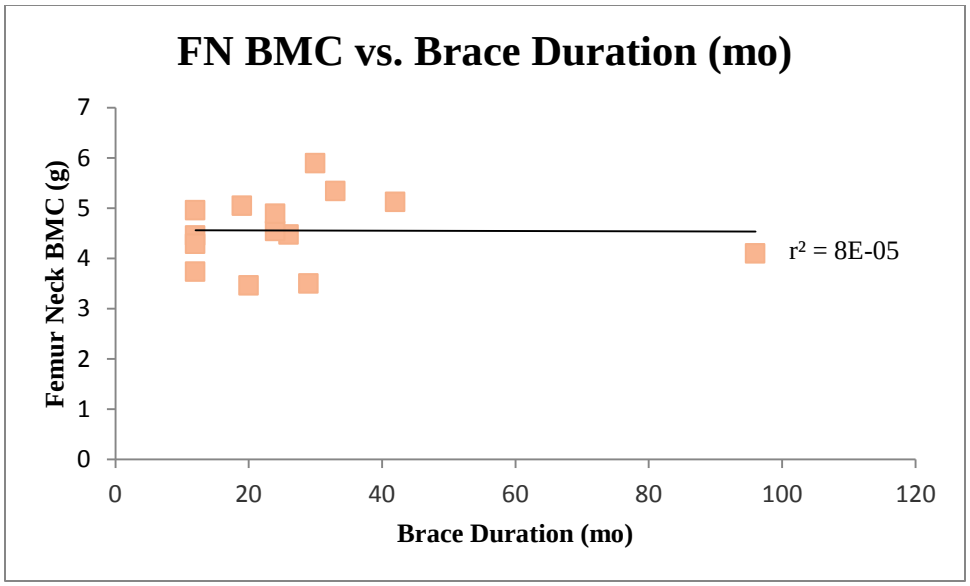

Figure 4.3: Scatterplot for femur neck BMC and brace wear in total number of months for the AIS-braced group.

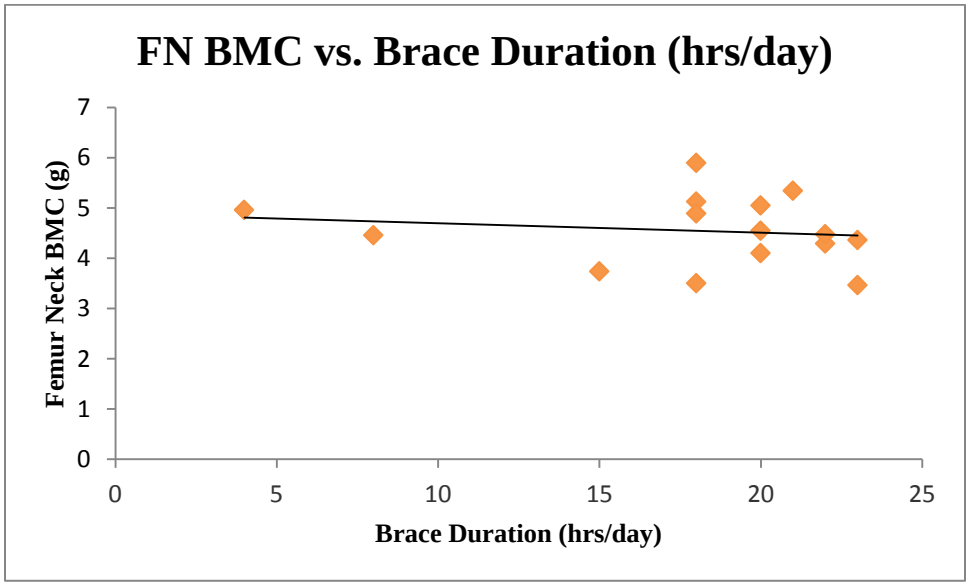

Figure 4.4: Scatterplot for femur neck BMC and brace wear in hours/day for the AIS-braced group.

Ratios for peripheral to axial BMC were also computed to identify differences in the distribution of bone mineral content between different skeletal regions (table 4.7) for

the different groups. The ratios for the legs (lower limbs) vs. spine BMC yielded similar means for the braced, not-braced and the control groups. Likewise, the ratios for the arms (upper limbs) vs. spine BMC were similar for all groups. Overall, there were no significant differences in the BMC of the peripheral to axial ratios ($p > .05$).

Table 4.7: The ratios of peripheral (legs and arms) vs. axial (spine-L1-L4)

	Braced (n=15)	**Not-braced (n=15)**	**Control (n-19)**	**ANOVA**
Arms/Spine (L1-L4) ratio:	4.67 ± 0.46	4.84 ± 0.50	4.75 ± 0.60	.72
Legs/Spine (L1-L4) ratio:	13.63± 1.48	14.42 ± 2.06	14.65 ± 1.94	.40

Note: BMC ratios presented as means ± SD for braced, not-braced and control groups

4.6 Quantitative Ultrasound Results

Tibial SOS for the three groups is plotted in Figure 4.3. There was a significant difference between the three groups ($p < .01$). The AIS groups displayed significantly greater tibial SOS compared with controls. These differences remained significant after controlling for lean body mass, strenuous physical activity, physical activity at intensity 3, Ca^{++} and vitamin D (ANCOVA).

For radial SOS there was a marginal significant difference between the three groups ($p = .05$), which was significant after controlling for LBM, Ca^{++}, Vit. D, intensity 4 physical activity and strenuous exercise ($p = .04$). The braced group (4168.87 ± 21.41) had higher SOS values compared to the non-braced (4105.56 ± 20.68) and control group (4096.18 ± 18.53). Results for the adjusted radial SOS are plotted in Figure 4.4.

4.7 DXA vs. QUS

Scatter plots were used to examine the association between peripheral bone propertis (radial and tibial SOS), as measured by QUS, and peripheral (arm and leg) BMC, as measured by DXA, within each group. No significant associations between SOS and BMC data were observed (see Appendices 3.15 and 3.16)

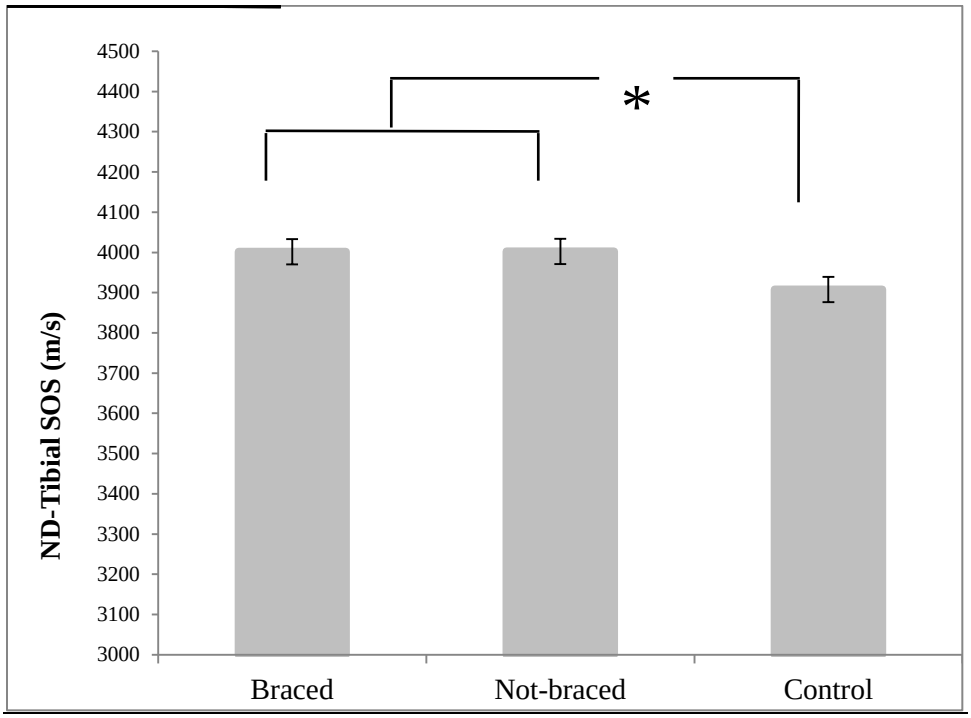

Figure 4.5: Non-dominant tibial SOS of the braced, not-braced and control females (mean ± SD; *$p < .01$).

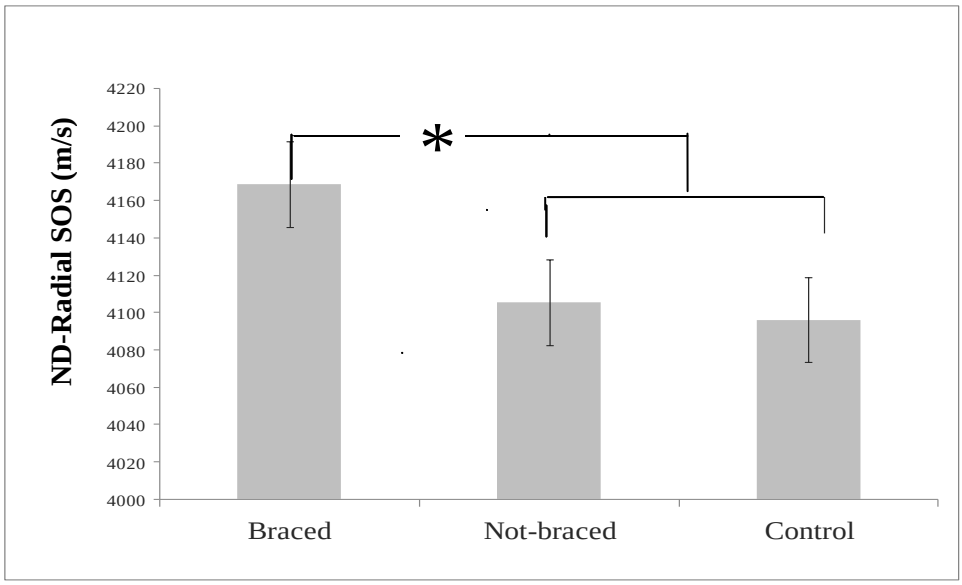

Figure 4.6: Non-dominant radial SOS of the braced, not-braced and control females, adjusted for lean body mass, vitamin D, calcium, intensity-4 physical activity, and strenuous exercise (mean ± SD; *$p < .05$).

Chapter 5: Discussion

5.1 Strengths/Uniqueness of the Study

The current study examines BMC, BMD and bone strength in young women with AIS who had been treated with a brace during their adolescence. By design, the current study has addressed many of the individual and overall limitations of the studies mentioned previously (Chapter 2), making the current study unique as follows:

1. The current study looks at the effects of bracing after the women had grown beyond the age of peak rate of bone accrual.
2. The current study examines Caucasian females only, to make the results applicable to a population that is most affected by AIS.
3. The current study assesses bone mass and quality using two different technologies: DXA is generally used to examine skeletal sites characterized mainly by trabecular bone while QUS is used to examine sites characterized mainly by compact bone.
4. The current study goes beyond measuring BMC at just the FN and LS, it adds further to the current literature on bone health in AIS by examining BMC in the upper and lower limbs and of the whole body.

5.2 Main findings

When assessing bone health in AIS patients, typically the spine and hip are the main regions measured. Our study not only took into account these primary measuring sites but also examined the upper and lower limbs. The results of the current study showed decreased femoral neck BMC in the AIS-braced group, with a similar pattern in other sites (Wards triangle, femur shaft, legs). Lower BMC levels were noted at the lower

limbs of the AIS-braced group, with no difference in spinal and upper limbs BMC between groups. Finally, there were no significant correlations between brace wear time and BMC at any of the sites so it seems unlikely that brace wear is the causal mechanism explaining the lower BMC.

5.3 Femoral Neck (FN) BMC

There were no significant differences between groups in the FN BMC and BMD. This is in agreement with early studies that investigated the effects of one year of bracing on BMC/BMD in adolescent girls, and concluded that brace treatments do not affect BMD at the spine and hip (Snyder et al., 1995; Snyder et al., 2005). However, once femur neck BMC was adjusted to lean body mass, calcium and vitamin D daily intake, as well as past and present strenuous physical activity, significantly lower BMC was noted in AIS-braced compared with AIS-not braced and the control group. This is in agreement with Courtois et al., who examined the effects of bracing in a population similar in age to our participants (age 30.5 ±6), and reported that AIS-braced patients had statistically lower spinal BMD values and consistently lower BMD at all the measurement sites than healthy women. They concluded that bracing during adolescence hindered bone mass accrual (Courtois et al., 1999). The current study did not find any significant associations between femur neck BMC and brace wear measured in total months and in hours/day, and degree or curvature, as measured using a scoliometer. These results are in agreement with previous study by Snyder et al. and Courtois et al., (Snyder et al., 1995; Snyder et al., 2005; Courtois et al., 1999)

Our results contradict the studies by Snyder et al. who investigated the effects of one year of bracing on BMC/BMD in adolescent girls, and concluded that brace treatments do not affect BMD at the spine and hip (Snyder et al., 1995; Snyder et al., 2005). The main issues with their results is that they assessed the effects of bracing only after 1 year of brace treatment, compared to the results of our study that examined the effects of bracing in females who were all past the critical growth period. In their 2005 study, Snyder et al. examined the rate of increase in BMC and they reported that the girls who received brace treatment have lower annual increase in BMD in the FN compared a healthy control group of another study. This further supports our findings that braced females have overall lower BMC in the FN. A similar pattern was observed in the femur shaft, ward's triangle and legs, although the differences between groups did not reach statistical significance.

The current study extends these findings because it takes into account mitigating factors that can affect bone parameters. The study by Courtois et al., did not assess dietary intake in particular calcium and vitamin D, nor did they report their data or the methods used for assessing physical activity levels (Courtois et al., 1999). These factors play a very important role in bone accrual.

5.4 Lumbar Spine (LS) BMC

In contrast to our hypothesis, we did not find any difference in the LS BMC between the three groups. This is in agreement with finding from the studies by Snyder et al. in 1995 and 2005, but contradicts the result reported by Qui et al., and Sun et. al., who reported an increase in BMC/BMD at the FN and LS in adolescent girls after 1.1 years of

bracing (Sun et al., 2006, Qiu et al., 2008). However, unlike the current study, the above two studies did not have a healthy control group and thus their results need to be interpreted with caution. Courtois et al., however, observed lower BMD at the LS (L2-L4) in their AIS braced group (Courtois et al., 1999). Their study was similar in design to the current study. They suggested that that the low bone mass was associated with the severity of the curvature (Courtois et al., 1999). In the current study we did not see any association between curvature as measured via scoliometer and BMC levels at the FN in any of the groups (Appendix 3.23 to 3.25).

Spinal BMD values, as determined with DXA, should be interpreted with caution. This is due to the fact that when the lateral curvature is accompanied by a rotation in the spine, as is often the case in AIS, this can affect the DXA results. DXA only projects the three-dimensional bone structure into a two-dimensional image. Therefore, the measured BMD in the spine is likely to be affected by any deformity or axial rotation of the vertebrae (Cheng et al., 2000). The measured change may be as high as 20% (Girardi et al., 2001). In 1995, Snyder and his colleagues scanned six human vertebras in the sagittal plane and concluded that at axial rotations beyond 25 degrees the pedicles came into view of the scan, influencing the bone parameters, and resulted in larger errors in BMD/BMC values. The differences between the frontal and sagittal plane spinal BMD ranged from 10 to 60% (Snyder et al., 1995). In an observational study the quantitative effects of axial rotation of lumbar vertebrae on BMD and BMC was examined using DXA in the anteroposterior plane, with vertebral axial rotation in increments of 7.5 degrees, up to a maximum of 45 degrees. A significant negative correlation between the degree of rotation and BMD, but not BMC, was noted. BMD decreased approximately 19% when

the vertebrae were rotated by 45 degrees (Cheng, Sher, Guo, Hung, & Cheung, 2001). Their results suggest that measurements of lumbar spine bone mineral content by DXA are not affected by axial rotation, while bone mineral density measurements are not reliable. This implies that BMD results reported by Courtois et al.,(1999) should be interpreted with caution.

5.5 Mitigating Factors: Physical Activity and Nutritional Intake

There are several mitigating factors that can affect bone health including nutrition, physical activity, body composition and age. By design, the effects of age were controlled for since our participants in the each group were similar in age. Furthermore, no differences between groups were observed in nutrition and physical activity. The current study is the only study to have examined all these mitigating factors in the investigation of bone health in women with AIS.

5.5.1 Dietary Intake and Bone Health

Dietary intake is an important modifiable factor for bone health. In general, a bone-healthy diet consists of consuming enough calories for adequate weight and adequate amounts of calcium and vitamin D (Cashman, 2007). Adequate calcium and vitamin D intake is critical to achieving optimal peak bone mass in the growing years. Our study assessed the current diet, particularly total energy intake (EI), vitamin D and calcium intake, between the groups to see if any of the differences in bone mass and bone strength could be explained by calcium and vitamin D intake. We did not see significant differences between the braced, not-braced and control group in daily total energy intake, calcium intake or dietary vitamin D intake (Table 4-3). Additionally, there was no

significant difference for supplemental calcium and vitamin D intake between the three groups. Past dietary intake was not assessed in the current study, as it is impossible in such a cross-sectional study of adults to ask subjects to recall food intake over a longer time period. This is especially true for females between the ages of 12-20yrs, which are characterized by significant changes in lifestyle (New et al., 2000).

No correlation was observed between calcium intake and BMC of the upper and lower limbs, total body, femur shaft and LS ($p < .05$). This may be explained by the fact that most participants reported sufficient calcium intakes. All groups in the current study had mean calcium intakes that were above the recommended daily intake (RDI) of 1000 mg for ages 19-55 years according to Health Canada, 2012, (Table 4-3).

Previous studies that have looked at the effects of bracing on bone health have failed to assess and or report the total EI, vitamin D and Ca^{++} (Courtois et al., 1999; Qiu et al., 2008; Sun et al., 2006). The studies by Snyder et al., (1995 and 2005) were the only ones that assessed nutritional parameters and calcium intake, and in both studies they noted no significant difference between the groups, however they did not performs correlations at analysis between the nutritional and bone parameters.

5.5.2 Physical Activity and Bone Health

The current study assessed current and past physical activity using the Godin-Shephard leisure time physical activity questionnaire and the lifetime physical activity questionnaire, respectively. Although there were no significant group differences between the braced, not-braced and control group in their levels of current and past physical activity (Table 4.4), the AIS groups did have a tendency to have lower past and present physical activity. This trend, although not significant, was especially apparent in

the AIS-braced group, while the absence of significance may be due to the insufficient statistical power due to the relativity small sample size in this study. The benefits of physical activity on bone health have typically been assessed by measuring the association of physical activity level with bone mass and strength (Bailey, 1997). It is our speculation that the lower levels of weight bearing physical activity could explain the low levels of BMC in the FN and the lower limbs. Therefore, the results of the AIS braced females having low levels of BMC at the weight bearing FN and lower limbs and not LS and upper limbs in the current study, suggests that site-specific factors may be acting on the bone. The "set-point" for the effects of various stress levels on bone, as defined in the Mechanostat theory (Frost 1987), may not be constant and may vary from site to site (Ruff, 2006; Skerry, 2006), suggesting that each skeletal site responds different to immobilization and in this case immobilization via brace treatment. Weight-bearing, high-impact physical activity is beneficial to bone accretion, especially at weight-bearing sites of the skeleton (Bailey et al., 1996; Bailey, 1997; Bailey et al., 1999; Courteix et al., 1998; Fuchs, Bauer, & Snow, 2001; Kohrt et al., 2004; Morris et al., 1997; Slemenda, Miller, Hui, Reister, & Johnston, 1991; Slemenda et al., 1994). Of the studies that examined the effects of bracing on bone (Table 2.2), only a few studies assessed physical activity and reported no differences between the AIS braced group and control groups (Snyder et al., 1995; Snyder et al., 2005, Courtois, Collet, Mouilleseaux, and Alexandre, 1999). It is possible that brace wear does not adversely affect an individual's ability to perform daily physical activity, but it may hinder their ability to perform high impact weight bearing physical activity.

5.6 Quantitative Ultrasound: Tibial and Radial SOS

Contrary to our expectations and to previous research, our results show higher tibial SOS in the AIS groups ($p < .05$) compared to the normal controls. A similar pattern was observed in the radius, although this difference was statistically significant only after controlling for lean body mass, strenuous physical activity, physical activity, and daily Ca^{++} and vitamin D intake ($p < .05$). This was especially apparent in the braced group. To our knowledge, Lam and his colleagues (Lam et al., 2011) are the only ones that have assessed bone quality using QUS in AIS adolescents, in a case control study. Their results showed that VOS (also known as SOS) in the AIS groups were 0.5 % lower than that of the control group (Lam et al., 2011). One factor contributing to the discrepancy between our SOS results and those of Lam et al is that two different sites were measures. i.e., Lam et al measured calcaneus, which is mostly trabecular bone, whereas we measured the radius and tibia, which are mostly cortical bone. Additionally, different techniques were used (transverse vs. transaxial). Nevertheless, we do not have an explanation for the higher SOS in cortical bone in the AIS-B group.

No statistically significant correlations were observed between SOS and DXA values. These results are in agreement with Cook et al. (2005) who concluded that the Sunlight Omnisense QUS measurement (proximal phalanx, distal radius and mid-shaft tibia) correlated poorly with Hologic DXA(L1-L4) (r=0.127–0.340) in postmenopausal women (Cook et al., 2005). Similarly, Wang and his colleagues assessed the validity BUA and SOS, parameters of QUS to DXA and pQCT in 258 pre-pubertal girls and nine adults and concluded that calcaneal BUA but not SOS is comparable to DXA and pQCT

(Wang et al., 2005). Studies in other populations have yielded similar results (DiVasta et al., 2007). Most studies compared DXA to QUS using calcaneus BUA and not SOS of the tibia or radius. It should be noted that BUA is a transverse measurement, measuring through the bone and as a result measurements are influenced by the size of the bone, whereas the tibial and radial SOS used in our study is a transaxial measurement, which is thus not influenced by the size of the bone.

However, we speculate that the discrepancy may be explained by the limitation posed by the two different bone assessment techniques. DXA measurements reflect both compact and trabecular bone. Tranaxial SOS, on the other hand, reflects only cortical bone. Our DXA results showed that FN, which is mostly trabecular, was lower in the AIS braced group, while SOS of the tibia, which is mostly cortical, was higher in AIS. Studies that have measured vBMD using pQCT have shown that unlike trabecular bone, cortical vBMD only changes slightly during pubertal growth and remains almost constant throughout adult life (Schoenau & Fricke, 2008; Wang et al., 2005). This would suggest that the possible effects of bracing, physical activity and nutrition are likely reflected in the trabecular FN BMC and not the tibial SOS. Thus, it is perhaps this discrepancy that accounts for the paradoxical results noted in the current study between DXA and SOS measurements.

5.7 Limitations

There are several limitations inherent in the present study. The main limitation of the current study is that it is a non-experimental, cross sectional study and thus we are unable make cause-and-effect conclusions. The low sample size and low statistical

power affects the strength and associations of our findings and may reduce the probability of finding a statistical significance between the groups. Nevertheless, group differences in BMC were observed in the femoral neck axis, with a similar trend in other skeletal sites. We did not measure past nutritional intake for daily calcium, vitamin D and energy intake and these factors are vital in bone health during the growing years of a child. Data regarding past diet would have allowed for us to control for the effects of the above mitigating factors on bone in an effort to find the true effects of bracing on bone health.

5.8 Conclusion

This is one of the few studies to examine BMC/BMD and bone strength in young women with AIS who had been treated with a brace during their adolescence, using DXA and QUS, and to compare their results between three groups: AIS-braced, AIS not braced and a healthy control groups. Our findings suggest that young women with AIS, especially those who were treated with a brace during their growing years, are characterized with low BMC in the lower limbs. This finding could not be explained by nutrition, physical activity, brace wear time or body composition. The lack of a relationship between bracing duration during adolescence and BMC during young adulthood suggests that the brace treatment is not the likely cause of the low BMC.

5.9 Clinical Implications

The parents and medical providers of adolescents who have AIS are often faced with decisions regarding the treatment choice for their child's scoliosis. Research has

consistently demonstrated low bone status in AIS, while there are contradictory results in studies examining the effects of bracing on bone health. The result of the current study suggest that while bone status may be low in girls with AIS, this status is likely not exacerbated by the bracing itself. Furthermore, in our sample, bracing did not seem to affect the amount of physical activity, suggesting that although bracing may be uncomfortable and perceived to be impeding, engagement in physical activity is possible and can be encouraged in order to maximize the effects of physical activity on bone health during a period of growth.

5.10 Future Research

Further research is needed to address the cause-and-effect relationship between brace treatment and bone health. With the limitations of the current study and those of previous studies in mind, future longitudinal and follow-up studies with larger sample sizes (53 ≥), using technology such as QCT in place of DXA and QUS, are needed in order to look at the effects of bracing during adolescence into adulthood.

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Appendix 1: Brock University Research Ethics Board Clearance Application

Brock University
Research Ethics Office
Tel: 905-688-5550 ext. 3035
Email: reb@brocku.ca

Bioscience Research Ethics Board

Certificate of Ethics Clearance for Human Participant Research

DATE:	11/17/2011
PRINCIPAL INVESTIGATOR:	FALK, Baraket - Kinesiology
FILE:	11-045 - FALK
TYPE:	Faculty Research

TITLE: Scoliosis and bone mineral density

ETHICS CLEARANCE GRANTED

Type of Clearance: NEW Expiry Date: 11/30/2012

The Brock University Bioscience Research Ethics Board has reviewed the above named research proposal and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement. Clearance granted from 11/17/2011 to 11/30/2012.

The Tri-Council Policy Statement requires that ongoing research be monitored by, at a minimum, an annual report. Should your project extend beyond the expiry date, you are required to submit a Renewal form before 11/30/2012. Continued clearance is contingent on timely submission of reports.

To comply with the Tri-Council Policy Statement, you must also submit a final report upon completion of your project. All report forms can be found on the Research Ethics web page at http://www.brocku.ca/research/policies-and-forms/research-forms.

In addition, throughout your research, you must report promptly to the REB:

a) Changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) All adverse and/or unanticipated experiences or events that may have real or potential unfavourable implications for participants;
c) New information that may adversely affect the safety of the participants or the conduct of the study;
d) Any changes in your source of funding or new funding to a previously unfunded project.

We wish you success with your research.

Approved:

Brian Roy, Chair
Bioscience Research Ethics Board

Note: Brock University is accountable for the research carried out in its own jurisdiction or under its auspices and may refuse certain research even though the REB has found it ethically acceptable.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and clearance of those facilities or institutions are obtained and filed with the REB prior to the initiation of research at that site.

Appendix 2: Questionnaires and Forms

Appendix 2.1: Letter of Invitation

Scoliosis and bone mineral density

Principal Investigators: Bareket Falk, Department of Kinesiology, Brock University and Alan Rigby, Niagara Prosthetics and Orthotics Corp.

We, Bareket Falk from the Department of Kinesiology, Brock University, and Alan Rigby, from Niagara Prosthetics and Orthotics Corp, invite you to participate in a research project entitled Scoliosis and bone mineral density.

The purpose of this research project is to **examine bone mineral density among young adults who had suffered from scoliosis** as adolescents and had worn a brace for an extended period of time. Should you choose to participate, you will be asked to undergo a bone mineral density scan and complete several questionnaires.

Participation in the study would entail one visit to the CML HealthCare Clinic, on Pelham Rd., St. Catharines (about 90 min).

Potential benefits include gaining general knowledge about the human body, as well as specific knowledge about your bone strength.

The study is funded by Federal Economic Development Agency for Southern Ontario

If you have any pertinent questions about your rights as a research participant, please contact the Brock University Research Ethics Officer (905 688-5550 ext 3035, reb@brocku.ca)

If you are interested in participation, or would like some more information, please feel free to contact me (see below for contact information).

Thank you,

Bareket Falk, Ph.D.
Professor
Department of Kinesiology
Brock University
500 Glenridge Ave.
St. Catharines, ON
L2S 3A1
905-688-5550 ext: 4979
bfalk@brocku.ca

Alan Rigby
Secretary
Niagara Prosthetics and Orthotics
547 Glenridge Avenue
St Catharines, Ontario
L2T 4C2
905 688-2553
alanrigby@niagarapo.ca

This study has been reviewed and received ethics clearance through Brock University's Research Ethics Board **(#11-045).**

Please retain this letter for your reference.

Appendix 2.2: DXA Requisition Form

DXA requisition Form

Date: _____

Please order the following dual energy X-ray absorptionmetry (DXA) scans:
__ full body
__ hip
__ spine
For the research participant, _____ (participant's full name), who is enrolled in the study entitled: "Scoliosis and bone mineral density". The principal investigator of this study is: Bareket Falk. The study has received REB clearance from Brock Universiy REB# 11-045.

The study includes 1 whole body scan, a hip and a spine scan for each participant. Scans will be performed at CML HealthCare (245 Pelham Rd, St. Catharines), using a GE Lunar Prodigy DXA bone densitometer (GE Lunar Corporation, Madison, WI). All scans will be performed by Robin Buzanko, a qualified, certified technician.

_____
Matt Greenway, MD

_____
Date

Appendix 2.3: Information & consent to participate in research

INFORMATION & CONSENT TO PARTICIPATE IN RESEARCH

Scoliosis and bone mineral density

You are being invited to participate in a research study being conducted by the investigators listed below. Prior to participating in this study please read this form to find out about the purpose and the tests of this study. This study is part of the Faculty of Applied Health Sciences of Brock University.

INVESTIGATOR:	**DEPARTMENT:**	**CONTACT:**
Dr. Bareket Falk	FAHS, Brock U	688-5550 x4979
Alan Rigby	Niagara Prosthetics and Orthotics	688-2553

PURPOSE:

The objective of this study is to determine the nature and extent of the relationship between brace treatment of scoliosis and BMD. That is, we propose to examine whether bracing during adolescence results in low BMD in young adulthood and whether this effect is related to the duration and compliance to bracing.

DESCRIPTION OF TESTING PROCEDURES:

If you agree to volunteer for this study you will partake in two testing sessions.
One session will take place at the Applied Physiology Laboratory (WH23, Brock University)(approximately 60 min), while the other will take place at Medvue Medical Imaging (Lake St., St. Catharines)(approximately 30 min).

At the end of the study, you will be given a summary of the findings, upon request. You will be reimbursed for your travel expenses ($50).

You will undergo the following measurements or procedures:

1. Completing several questionnaires, outlining your medical history, past and present physical activities and nutritional habits. In all questionnaires, you may chose not to answer any question without penalty.
2. Determination of bone properties (bone strength) using the Sunlight BonAge™ ultrasound system. This procedure involves the application of gel to the forearms and the lower legs and passing an ultrasound probe over these regions. This procedure is quick and causes no discomfort.
3. Bone mineral density (BMD) will be assessed at CML Medical Imaging (Pelham Rd., St. Catharines). Total body, hip and spine BMD, and body composistion will be measured using four scans. These scans are standard clinical procedures and require about 15-20 minutes. A DXA scan involves some exposure to radiation. The radiation dose is similar to the amount of radiation exposure as taking a trans-continental flight.

CONFIDENTIALITY:

All your data collected during this study will remain confidential and will be stored in offices and on secured computers to which only the principal and co-investigators have access. You should be aware that the results of this study will be made available to scientists, through publication in a scientific journal but

your name and any personal data of you will not appear in compiling or publishing these results. Data will be kept for 5 years after the date of publication, at which time all hard copy data will be destroyed. Additionally, you will have access to your own data, as well as the group data when it becomes available and if you are interested.

PARTICIPATION & WITHDRAWAL

You can choose whether to participate in this study or not. You may remove your data from the study if you wish. You may also refuse to answer any questions posed to you during the study and still participate in the study. The investigators reserve the right to withdraw you from the study if they believe that it is necessary.

RISKS AND BENEFITS

There are no foreseeable risks in participation in this study. Nevertheless, it should be noted that a DXA scan involves some exposure to radiation. The radiation dose is commonly refered to as the effective radiation (measured in units of mSv). The effective dose of each DXA scan is 0.001mSv, which is similar to the amount of radiation exposure as taking a return trans-continental flight. The associated risk is considered negligible.
Participation will allow you to gain personal and general knowledge about the human body, and specifically, about bone strength. Additionally, if an unusually low or high result is attained for any of the measurements, reflecting a possible health-related problem, you will be alerted and advised by our physician. All results will be provided to you upon request.

If you have had a barium X-ray within the past two weeks, if you are using a pacemeaker, of if you think you may be pregnant, you are not eligible to participate in this study.

RIGHTS OF RESEARCH PARTICIPANTS

You will receive a signed copy of this ethics form. You may withdraw your consent to participate in this study at any time, and you may also discontinue participation at any time without penalty. In signing this consent form or in participating in this study you are not waiving any legal claims or remedies. This study has been reviewed and received clearance from the Brock University Research Ethics Board (file # 11-045). If you have any pertinent questions about your rights as a research participant, please contact the Brock University Research Ethics Officer (905 688-5550 ext 3035, reb@brocku.ca)

INFORMATION:

Please contact Dr. Bareket Falk at 905-688-5550(X: 4979), or Alan Rigby at 905-688-2553 if you have any questions about the study.

I HAVE READ AND UNDERSTAND THE ABOVE EXPLANATION OF THE PURPOSE AND PROCEDURES OF THE PROJECT. I HAVE ALSO RECEIVED A SIGNED COPY OF THE INFORMATION AND CONSENT FORM. MY QUESTIONS HAVE BEEN ANSWERED TO MY

SATISFACTION AND I AGREE TO PARTICIPATE IN THIS STUDY.

SIGNATURE of PARTICIPANT DATE

INVESTIGATOR

In my judgment the participant is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent and participate in this research study.

SIGNATURE OF INVESTIGATOR DATE

Appendix 2.4: Scoliosis and DXA screening questionnaire

Scoliosis and bone mineral density

SCREENING QUESTIONNAIRE

Your responses to this questionnaire are confidential and you are asked to complete it for your own health and safety. You may refuse to answer any of the following questions.

Name: _____ Date: _____

☐ Male ☐ Female

1. Is there any chance you might be pregnant? ☐ Yes ☐ No
2. Have you had a barium X-ray in the past 2 weeks? ☐ Yes ☐ No
3. Have you had a nuclear medicine scan or X-ray dye in the last week?
   ☐ Yes ☐ No
4. Have you ever had surgery of the spine, hips, arms or legs?
   ☐ Yes ☐ No
5. Have you ever had a bone density test before? ☐ Yes ☐ No
   When? _____
   Where? _____
6. Have you broken any bones? ☐ Yes ☐ No
   If yes, which bone(s) _____
7. Is there any medical condition with which you have been diagnosed and are under the care of a physician (e.g. diabetes, high blood pressure)?
   ☐ Yes ☐ No
8. Has your father / mother / brother / sister ever had osteoporosis?
   ☐ Yes ☐ No
9. Are you, or have you in the past, engaged in any extreme diet?
   ☐ Yes ☐ No
10. Have you had a history of longstanding malnutrition or malabsorption?
    ☐ Yes ☐ No
11. Have you ever had chemotherapy? ☐ Yes ☐ No
12. Do you have hyperparathyroidism? ☐ Yes ☐ No
13. Is your period regular? ☐ Yes ☐ No
    If not, please specify: _____
    Age of menarche (first period): _____
14. Do you, or have you in the past, smoked on a regular basis?
    ☐ Yes ☐ No
15. Do you, or have you in the past, consumed any alcohol on a regular basis?
    ☐ Yes ☐ No
16. Are you taking any of the following medications?

Medication	Taking	Dose	How long?
Calcium supplement	☐ Yes ☐ No		
Vitamin D supplement	☐ Yes ☐ No		
Fosamax Fosavance (Alendronate)	☐ Yes ☐ No		
Actonel (Risedronate)	☐ Yes ☐ No		
Didrocal Dironel (Etidronate)	☐ Yes ☐ No		
Evista (Raloxifene)	☐ Yes ☐ No		
Calcitonin Spray	☐ Yes ☐ No		
Biophosphonate (injection/infusion)	☐ Yes ☐ No		
Thyroid Tapazole PTU	☐ Yes ☐ No		
Aclasta (zoledronate)	☐ Yes ☐ No		
Birth control pill Specify: _____	☐ Yes ☐ No		

Appendix 2.5: Scoliosis Screening Questionnaire

Scoliosis and bone mineral density

SCOLIOSIS BACKGROUND QUESTIONNAIRE

Your responses to this questionnaire are confidential. You may refuse to answer any of the following questions.

Name: ———————————— Date: ————————————

1. At what age were you diagnosed with scoliosis? _____ yrs.

2. At what age were you prescribed a brace? _____ yrs

3. What kind of brace did you have?

☐ Custom-made by Facility
☐ Boston
☐ Milwaukee
☐ Charleston
☐ other _____
☐ Don't Know

4. How long did you wear the brace?
_____ yrs and _____ months.

5. On average, how many hours/d did you wear the brace?
_____ hrs/d.

6. Did you have corrective surgery and/or rods surgically implanted in your spine?
☐ Yes ☐ No

7. Who was the attending Medical Physician? _____
Can we have authorization to contact the physician to find the Cobb Angle?

☐ Yes ☐ No

Appendix 2.6: Godin-Shephard Leisure-Time Exercise Questionnaire

GODIN-SHEPHARD LEISURE-TIME EXERCISE QUESTIONNAIRE

1. Considering a **7-day period** (a week), how many times on the average do you do the following kinds of exercise for **more than 15 minutes** during your **free-time** (write on each line the appropriate number)?

Times Per Week

(a) STRENUOUS EXERCISE
(HEART BEATS RAPIDLY)

_____

(i.e. running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling)

(b) MODERATE EXERCISE
(NOT EXHAUSTING)

_____

(i.e. fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, popular and folk dancing)

(c) MILD EXERCISE
(MINIMAL EFFORT)

_____

(i.e. yoga, archery, fishing from river bank, bowling, horseshoes, golf, snow-mobiling, easy walking)

2. Considering a **7-day period** (a week), during your leisure-time, how often do you engage in any regular activity long enough to work up a sweat (heart beats rapidly)?

1. OFTEN	**2. SOMETIMES**	**3. NEVER/RARELY**
☐	☐	☐

Appendix 2.7: The Lifetime Total Physical Activity Questionnaire (LPAQ)

Please DO NOT write your name or student ID on any of the questionnaires. All information collected will be kept confidential and anonymous.

THE LIFETIME TOTAL PHYSICAL ACTIVITY QUESTIONNAIRE

This Questionnaire is about physical activity patterns over your lifetime. Specifically about you occupational, household and exercise/sports activities.

PART 1: Occupational Activity

In this part, please tell us about your occupational activities. Please write down what jobs (paid or volunteer) you have done **at least 8 hours a week for four months of the year** over your life time. Start with your first jobs and end with the job that you had this year. Please describe the job that you had, the age that you started working at this job and the age when you ended doing this particular job. For each job we also need to know that number of years, the number of months per year, the number of days per week, the number of hours per day and the intensity of the job.

No.	Description of Occupational Activity	Age Started	Age Ended	No. of Days/week	Time/Day		Intensity of Activity (1,2,3,4)*
					Hours	Minutes	
1							
2							
3							
4							
5							

*Intensity of occupational activity defined as:
1 = jobs that require only sitting with minimal walking;
2 = jobs that require a minimal amount of physical effort such as standing and slow walking with no increase in heart rate and no perspiration;
3 = jobs that require carrying light loads (5-10 lb or 2-5kg), continuous walking, mainly indoor activity and that would increase the heart rate slightly and cause light perspiration;
4 = jobs that require carring heavy loads (>10 lb or >5 kg), brisk walking, climbing, mainly outdoor activity, that increase the heart rate substantially and cause heavy sweating.

PART 2: Household Activities

In this part, please tell us about the household and gardening activities that you have done over your lifetime. Start with your past activity and then continue up to this year. Please include only those activities that you have done **at least 7 hours per week for 4 months of the year**. It may help you to consider what a typical day is for you. Then think about how many hours of household and gardening or yard work you do in a typical day. For seasonal activities, such as gardening, you can report those separately from all other household activities that are done all year.

No.	Age Started	Age Ended	Number of months/Year	Number of Days/Week	Times per day	Hours per day spent in activities that were in category: (2, 3, 4)*		
				Hours	Minutes	2	3	4
1								
2								
3								
4								
5								

*Intensity of household activity defined as:
1 = activities that can be done while sitting;
2 = activities that require minimal effort such as those done standing, sitting or with slow walking, that do not require much physical effort;
3 = activities that are not exhausting, that increase the heart rate slightly and that may cause some light perspiration;
4 = activities that increase the heart rate and cause heavy sweating such as those requiring lifting, moving heavy objects, rubbing vigorously for fairly long periods.

PART 3: Exercise/Sports Activities

In this part we like to know all your exercise or sports activities that you did during your lifetime starting with childhood and continuing to this year. Please report the activities that you have done at least **2 hours per week for at least 4 months per year**. Please tell us what exercise and sports activities you have done **at least 10 times** during your life time. Besides sports and exercise, we are also interested in knowing whether you walked or biked to school or work. If you have done this, please report all the information as for the other sports activities. Please begin by telling us the activities that you did during your school years including your physical education (gym) classes.

No.	Description of Exercise/Sports Activity	Age Started	Age Ended	Frequency of activity				Times per activity		Intensity of Leisure Activity (2,3, 4)*
				Day	Week	Month	Year	Hours	Minutes	
1										
2										
3										
4										
5										

*Intensity of exercise/spots activity defines as:
1 = activities that are done sitting;
2 = activities that require minimal effort;
3 = activities that are not exhausting, that increase the heart rate slightly and may cause some light perspiration;
4 = activities that increase the heart rate and cause heavy sweating;

Source: Friedenreich, C. M., Courneya, K. S., and Bryant, H. E. (1998). The Lifetime Total Physical Activity Questionnaire: development and reliability. *Medicine & Science in Sports and Exercise*, 30 (2), 266-274.

Comments:

THANK YOU!

Appendix 2.8: International Physical Activity Questionnaire (IPAQ)

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (October 2002)

LONG LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective.* Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** and **moderate** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

☐ ***Yes***

☐ No → ***Skip to PART 2: TRANSPORTATION***

The next questions are about all the physical activity you did in the **last 7 days** as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, heavy construction, or climbing up stairs **as part of your work**? Think about only those physical activities that you did for at least 10 minutes at a time.

_____ **days per week**

☐ No vigorous job-related physical activity → ***Skip to question 4***

3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

_____ **days per week**

☐ No moderate job-related physical activity → ***Skip to question 6***

5. How much time did you usually spend on one of those days doing **moderate** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

6. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **as part of your work**? Please do not count any walking you did to travel to or from work.

_____ **days per week**

☐ No job-related walking → ***Skip to PART 2: TRANSPORTATION***

7. How much time did you usually spend on one of those days **walking** as part of your work?

_____ **hours per day**
_____ **minutes per day**

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the **last 7 days**, on how many days did you **travel in a motor vehicle** like a train, bus, car, or tram?

_____ **days per week**

☐ No traveling in a motor vehicle → ***Skip to question 10***

9. How much time did you usually spend on one of those days **traveling** in a train, bus, car, tram, or other kind of motor vehicle?

_____ **hours per day**
_____ **minutes per day**

Now think only about the **bicycling** and **walking** you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the **last 7 days**, on how many days did you **bicycle** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No bicycling from place to place → ***Skip to question 12***

11. How much time did you usually spend on one of those days to **bicycle** from place to place?

_____ **hours per day**
_____ **minutes per day**

12. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No walking from place to place → ***Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY***

13. How much time did you usually spend on one of those days *walking* ***from place to place?***

_____ **hours per day**
_____ **minutes per day**

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the **last 7 days** in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, chopping wood, shoveling snow, or digging **in the garden or yard**?

_____ **days per week**

☐ No vigorous activity in garden or yard → ***Skip to question 16***

15. How much time did you usually spend on one of those days doing **vigorous** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, sweeping, washing windows, and raking **in the garden or yard**?

_____ **days per week**

☐ No moderate activity in garden or yard → ***Skip to question 18***

17. How much time did you usually spend on one of those days doing **moderate** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, washing windows, scrubbing floors and sweeping **inside your home**?

_____ **days per week**

☐ No moderate activity inside home → ***Skip to PART 4: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY***

19. How much time did you usually spend on one of those days doing **moderate** physical activities inside your home?

_____ **hours per day**
_____ **minutes per day**

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the **last 7 days** solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

_____ **days per week**

☐ No walking in leisure time → ***Skip to question 22***

21. How much time did you usually spend on one of those days **walking** in your leisure time?

_____ **hours per day**
_____ **minutes per day**

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like aerobics, running, fast bicycling, or fast swimming **in your leisure time**?

_____ **days per week**

☐ No vigorous activity in leisure time → ***Skip to question 24***

23. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?

_____ **hours per day**
_____ **minutes per day**

24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?

_____ **days per week**

☐ No moderate activity in leisure time → ***Skip to PART 5: TIME SPENT SITTING***

25. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?

_____ **hours per day**
_____ **minutes per day**

PART 5: TIME SPENT SITTING

The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?

_____ **hours per day**
_____ **minutes per day**

27. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekend day**?

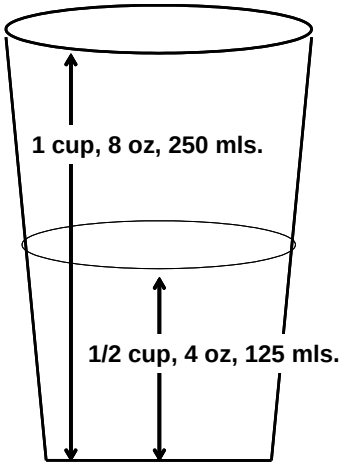
_____ **hours per day**
_____ **minutes per day**

This is the end of the IPAQ questionnaire, thank you for participating.

Appendix 2.9: RAM Questionnaire

Record the number of servings you ate on a typical day in the previous 7 days.
(Use the pictures to estimate serving sizes)

MILK -YOGURT-CHEESE	# SERVINGS DAILY
Cheese, 1oz or 6 tbsp.	
Cottage cheese, ½ cup	
Custard, pudding, or cream pie, ½ cup	
Ice cream, frozen yogurt, or milk shake, 1 cup	
Milk or cocoa, 1 cup	
Soy milk, 1 cup	
Yogurt, 1 cup	
Cream soups/sauce, 1 cup	
Macaroni and cheese, 1cup	
Pizza, 1/8 of 15" (8 slice pizza)	
Quiche, 1/8 of 8"	
FRUITS and VEGETABLES	**# SERVINGS DAILY**
Broccoli or cooked greens (beet/turnip greens, kale, collards, spinach), ½ cup	
Other vegetables, ½ cup	
Orange juice, 1 cup (enriched with calcium)	
Fruits, ½ cup or 1 small	
MEAL REPLACEMENT PRODUCTS	**# SERVINGS DAILY**
Slim fast, 1 can	
Jenny Craig bar, 1 bar	
Other:_____	
BREADS-CEREALS-RICE-PASTA	**# SERVINGS DAILY**
Bread, 1 slice	
Bread, 1 slice (enriched with calcium)	
Cereal, 1 oz	
Cereal, 1 oz (enriched with calcium)	
2" biscuit/roll	
6" corn tortilla	
3" muffin, cornbread, or doughnut	
Rice, noodles, or pasta, 1 cup	
Pancake, waffle, or French toast, 1 serving	



- **Fist = 1 cup or 1 medium whole fruit**
- **Thumb (tip to base) = 1 oz. of meat or cheese**
- **Thumb tip (tip to 1st joint) = tbsp.**
- **Index finger (1st to 2nd joint) = 1"**

FAT-SUGAR-ALCOHOL	# SERVINGS DAILY
Cake, 1/16 of 9”	
Beer, 12oz	
Colas, 12oz	
Chocolate, 1oz	
MEAT-FISH-POULTRY-DRY BEANS-NUTS	# SERVINGS DAILY
Dry beans, cooked (navy, pinto, kidney), 1 cup	
Meat, fish, poultry, 3 oz	
Peanuts, ½ cup	
Almonds, ½ cup	
1 egg	
Salmon (with bones), 3oz	
Sardine (with bones), 3 oz	
3oz shrimp	
7 to 9 oysters	
Tofu, 2 ½”x 2 ½”x 1”	

Appendix 2.10: 24-hour Nutritional Recall Questionnaire

24 Hour Nutritional Recall

Name: _____

Date: _____

Subject ID: _____

24 Hour Recall Date: _____

Nutritional Intake:

_____

_____

_____

_____

_____

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Appendix 3: Raw Data

Appendix 3.1: BMC values for each groups at the different skeletal site using DXA

	Brace (n=15)	Not-Braced (n=15)	Control (n=19)	ANOVA (p>0.05)	ANCOVA (p>0.05)
Head	487.79 ± 81.78	493.92 ±67.65	488.43 ±65.80	0.97	0.85
Arms	314.70 ± 74.64	324.44 ±53.64	314.81 ±33.20	0.85	0.84
Left arm	154.83 ± 38.19	157.75 ±27.30	153.66 ±16.72	0.91	0.86
Right arm	159.87 ± 36.81	166.69 ±26.81	161.16 ±16.91	0.76	0.78
Legs	911.40± 174.07	968.91±195.25	963.70±134.93	0.58	0.12
Left Leg	451.17 ± 38.19	479.27 ±94.03	480.68 ±67.23	0.54	0.09
Right leg	460.24 ± 85.28	489.64 ±101.62	483.02 ±68.29	0.61	0.17
Trunk	829.264 ± 232.91	875.45 ±242.49	888.38 ±156.78	0.70	0.39
Pelvis	314.46 ±75.66	347.36 ±98.76	352.20 ±64.58	0.36	0.16
Femur neck-axis	2.05 ± 0.32[a]	2.25 ±0.30	2.36 ±0.34[a]	0.03 *	0.01**
Femur neck	4.54 ±0.10[a]	4.89 ±0.61	5.07 ±0.58[a]	0.06	0.02**
Femur shaft	16.36 ±1.97	16.88 ±1.84	17.49 ±1.96	0.24	0.05
Femur trochanter	8.29 ±2.41	8.72 ±1.65	8.70 ±1.85	0.80	0.61
Femur wards	2.11 ± 0.49[a]	2.37 ±0.52	2.47 ±0.51[a]	0.11	.033**
Total femur	29.20 ±4.62	30.49 ±3.60	31.25 ±4.06	0.36	.104
L1	13.72 ± 2.88	14.25 ±2.76	13.60 ±2.24	0.76	.896
L2	15.56 ±2.92	15.71 ±3.01	15.87 ±2.74	0.95	.394
L3	18.31 ±3.62	18.81 ±4.0	18.04 ±2.96	0.81	.966
L4	19.73 ±4.06	18.76 ±3.81	19.94 ± 2.64	0.60	.124
L1-L4	67.32 ±13.02	67.53 ±12.03	67.46 ±10.23	0.99	.546
Total spine	267.47 ±66.04	263.84 ±60.00	258.42 ±42.18	0.89	.881
Total body	2543.15 ±522.47	2662.72 ±502.11	2655.32 ±323.82	0.71	.270

Values are presented as means ± SD; there were no significant differences between groups

*= ANOVA ($p \leq 0.05$); **=ANCOVA : total body lean mass, Ca+, Vit. D, Intensity 4 and strenuous exercise ($p \leq 0.05$)

[a]=group effect

Appendix 3.2: BMD values for each of the different skeletal sites using DXA

	Brace (n=15)	Not-Braced (n=15)	Control (n=19)	ANOVA (p>0.05)	ANCOVA (p>0.05)
Head	2.26 ±0.29	2.26 ±0.26	2.29 ±0.24	0.92	0.94
Arms	0.84 ±0.12	0.85 ±0.09	0.83 ±0.04	0.83	0.58
Left arm	0.82 ±0.12	0.84 ±0.09	0.82 ±0.04	0.86	0.70
Right arm	0.85 ±0.12	0.86 ±0.10	0.84 ±0.04	0.78	0.48
Legs	1.21±0.10	1.27±0.11	1.26±0.11	0.23	0.34
Left Leg	1.21 ±0.11	1.26 ±0.11	*1.26 ±0.08*	0.22	0.33
Right leg	1.22 ±0.10	1.27 ±0.11	1.26 ±0.08	0.27	0.38
Trunk	0.91 ± 0.09	0.92 ±0.09	0.93 ±0.05	0.76	0.97
Pelvis	1.13 ±0.11	1.14 ±0.12	1.17 ±0.09	0.56	0.78
Femur neck axis	0.92 ±0.12[a]	0.96 ±0.10	1.02 ±0.13[a]	0.04 *	0.12
Femur neck	1.00 ±0.11	1.02 ±0.09	1.08 ±0.10	0.07	0.17
Femur shaft	1.16 ±0.12	1.20 ±0.09	1.24 ±0.14	0.24	0.24
Femur trochanter	0.72 ±0.09	0.78 ±0.09	0.80 ±0.11	0.08	0.16
Femur wards	0.91 ±0.12	0.93 ±0.11	1.00 ±0.15	0.08	0.16
Total femur	0.97 ±0.10	1.02 ±0.08	1.05 ±0.11	0.06	0.15
L1	1.10 ± 0.13	1.14 ±0.14	1.15 ±0.12	0.50	0.63
L2	1.17 ± 0.13	1.23 ±0.11	1.24 ±0.13	0.29	0.42
L3	1.25 ± 0.13	1.23 ±0.08	1.27 ±0.12	0.60	0.67
L4	1.17 ± 014	1.18 ±0.12	1.22 ±0.11	0.45	0.78
L1-L4	1.17 ± 0.13	1.19 ±0.09	1.22 ±0.11	0.42	0.62
Total spine	0.98 ±0.13	1.02 ±0.14	1.07 ±0.09	0.07	0.11
Total body	1.13 ±0.09	1.15 ±0.8	1.15 ±0.06	0.67	0.84

Values are presented as means ± SD; there were no significant differences between groups
*= ANOVA ($p \leq 0.05$)
**=ANCOVA : total body lean mass, Ca+, Vit. D, Intensity 4 and strenuous exercise ($p \leq 0.05$)
a=group effect

Appendix 3.3: Whole group correlations (r) between BMC and anthropometric measures

	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Age at menerache (yrs)	TBF	TBM	TFM	TLM
Head	0.15	0.68	0.68	0.41	0.06	0.12	0.89	0.41	0.71
Arms	0.42	0.35	0.50	0.39	0.09	0.16	0.68	0.35	0.45
Left arm	0.15	0.68	0.68	0.42	0.08	0.12	0.89	0.41	0.72
Right arm	0.02	0.75	0.78	0.51	0.05	0.29	0.92	0.54	0.70
Legs	0.15	0.52	0.76	0.63	0.00	0.39	0.93	0.62	0.56
Left Leg	0.15	0.67	0.66	0.40	0.04	0.12	0.89	0.40	0.68
Right leg	0.01	0.76	0.76	0.48	0.07	0.23	0.90	0.50	0.73
Trunk	0.02	0.76	0.77	0.50	0.06	0.26	0.91	0.52	0.71
Pelvis	0.26	0.56	0.69	0.50	0.05	0.43	0.83	0.61	0.43
Femur neck-ax.	0.22	0.68	0.82	0.60	0.05	0.37	1.00	0.63	0.66
Femur neck	0.28	0.55	0.80	0.65	0.01	0.50	0.94	0.70	0.50
Femur shaft	-0.30	0.47	0.48	0.32	0.06	0.14	0.63	0.29	0.46
Femur troch.	-0.18	0.55	0.59	0.40	0.02	0.20	0.73	0.39	0.53
Femur wards	-0.12	0.55	0.53	0.32	0.11	0.09	0.76	0.30	0.58
Total femur	-0.13	0.60	0.57	0.35	0.04	0.11	0.80	0.33	0.61
L1	-0.10	0.52	0.49	0.28	-0.03	0.07	0.68	0.26	0.53
L2	-0.21	0.44	0.56	0.43	0.06	0.22	0.63	0.37	0.50
L3	0.22	0.69	0.55	0.25	0.20	0.01	0.78	0.27	0.68
L4	0.21	0.67	0.54	0.25	0.20	0.04	0.80	0.28	0.64
L1-L4	0.14	0.60	0.51	0.26	0.21	-0.02	0.73	0.24	0.66
Total spine	0.20	0.63	0.46	0.17	0.29	-0.04	0.74	0.20	0.61
Total body	0.25	0.66	0.55	0.27	0.04	0.06	0.66	0.29	0.64

AAM=Age at menerache; TBF= Total body fat; TBM=Total bone mass; TFM=total fat mass; TLM=Total lean mass; Femur neck-ax.=Femur neck axis; Femur troch.=Femur trochanter

Appendix 3.4: Whole groups correlations (r) between BMC and physical activity measures

	Godin-shephard LTEQ (hrs/wk)			IPAQ (METS)				LPAQ (intensity times/wk)			
	Mild	Mod	Stren.	Mod.	Vig.	Walk	Total	1	2	3	4
Head	0.19	0.00	0.17	-0.04	-0.13	-0.18	-0.16	0.18	-0.17	0.13	0.03
Arms	0.19	0.22	0.01	0.05	-0.13	-0.13	-0.10	0.21	-0.09	0.23	-0.03
Left arm	0.16	-0.02	0.16	-0.06	-0.14	-0.21	-0.19	0.15	-0.17	0.15	0.00
Right arm	0.27	-0.03	0.14	-0.13	-0.13	-0.22	-0.22	0.16	-0.13	0.23	0.16
Legs	0.33*	0.04	0.18	-0.12	-0.09	-0.19	-0.18	0.41*	-0.07	0.19	0.08
Left Leg	0.21	0.03	0.18	-0.02	-0.11	-0.15	-0.13	0.20	-0.17	0.10	0.06
Right leg	0.24	-0.07	0.15	-0.10	-0.08	-0.18	-0.17	0.16	-0.14	0.19	0.15
Trunk	0.25	-0.05	0.14	-0.12	-0.11	-0.20	-0.19	0.16	-0.14	0.21	0.15
Pelvis	0.38*	0.07	-0.08	0.01	-0.10	-0.06	-0.06	0.31	0.09	0.22	-0.13
FN- axis	0.32*	0.05	0.12	-0.04	-0.11	-0.18	-0.16	0.30	-0.08	0.23	0.05
Femur neck	0.37*	0.07	0.10	0.00	-0.07	-0.13	-0.10	0.41	0.02	0.20	-0.01
Femur shaft	0.21	-0.06	0.26	-0.35*	-0.15	-0.35*	-0.37*	-0.05	-0.10	0.07	0.27
Femur troch	0.25	-0.09	0.22	-0.29	-0.15	-0.32	-0.33	-0.01	-0.10	0.09	0.17
Femur ward	0.27	-0.07	0.26	-0.27	-0.15	-0.42*	-0.38*	0.03	-0.08	0.06	0.22
Total femur	0.26	-0.07	0.23	-0.20	-0.08	-0.37*	-0.31*	0.06	-0.01	0.12	0.18
L1	0.20	-0.04	0.14	-0.06	0.03	-0.25	-0.16	0.10	0.10	0.16	0.09
L2	0.12	-0.12	0.13	-0.27	-0.13	-0.27	-0.29	-0.08	-0.05	0.04	0.16
L3	0.35*	0.08	0.13	-0.08	-0.14	-0.06	-0.11	0.10	-0.04	0.10	0.07
L4	0.32*	0.05	0.08	-0.03	-0.13	-0.14	-0.14	0.13	0.00	0.13	0.08
L1-L4	0.31*	0.06	0.13	-0.10	-0.13	-0.17	-0.18	0.12	-0.06	0.12	0.06
Total spine	0.28	0.09	0.09	-0.13	-0.17	-0.09	-0.16	0.06	-0.04	0.13	0.09
Total body	0.39*	0.08	0.17	-0.05	-0.09	0.15	0.04	0.06	-0.05	0.01	0.02

LETQ=leisure-time exercise questionnaire; IPAQ=International physical activity questionnaire
LPAQ=life-time physical activity questionnaire
Mod.=Moderate; Vig.=Vigorous; Stren.=Strenuous
FN-axis.=Femur neck axis; Femur troch.=Femur trochanter

Appendix 3.5: Whole group correlation matrix between BMC and nutritional parameters

	24 hr. Recall Questionnaire							
	Energy Intake (Kcals)	Weight (g)	CHO (%)	Fat (%)	Calcium (mg)	Sodium (mg)	Protein (%)	Vitamin D (IU)
Head	-0.02	0.28	-0.16	-0.12	0.32	-0.09	0.01	0.23
Arms	-0.06	0.07	-0.20	-0.16	0.16	-0.18	-0.02	0.10
Left arm	-0.03	0.27	-0.17	-0.12	0.33	-0.12	0.01	0.24
Right arm	0.04	0.19	-0.20	-0.11	0.33	-0.11	0.02	0.21
Legs	0.09	0.10	-0.10	-0.05	0.30	-0.15	0.09	0.12
Left Leg	0.00	0.29	-0.15	-0.11	0.31	-0.06	0.01	0.22
Right leg	0.07	0.22	-0.23	-0.13	0.35	-0.11	-0.03	0.24
Trunk	0.05	0.20	-0.21	-0.12	0.34	-0.11	0.00	0.23
Pelvis	-0.04	0.24	-0.18	-0.13	0.23	-0.16	0.03	0.17
Femur Neck-Ax	0.01	0.16	-0.19	-0.12	0.31	-0.16	0.03	0.20
Femur neck	0.00	0.09	-0.13	-0.08	0.26	-0.17	0.07	0.15
Femur shaft	0.12	0.04	-0.03	0.06	0.17	-0.12	0.10	-0.07
Femur troch.	0.01	0.02	-0.04	0.05	0.14	-0.18	0.11	0.00
Femur wards	0.13	0.14	-0.08	0.01	0.30	-0.08	0.07	0.14
Total femur	0.10	0.25	-0.14	-0.06	0.30	-0.06	0.05	0.10
L1	0.08	0.39	-0.20	-0.16	0.28	0.01	0.00	0.07
L2	-0.03	0.01	-0.09	-0.01	0.10	-0.22	0.02	-0.02
L3	0.16	0.33	-0.23	-0.17	0.37	0.01	-0.06	0.14
L4	0.23	0.35	-0.21	-0.14	0.40	-0.01	-0.05	0.18
L1-L4	0.19	0.28	-0.21	-0.13	0.38	0.00	-0.05	0.10
Total spine	0.19	0.31	-0.22	-0.17	0.33	0.02	-0.04	0.19
Total body	0.03	0.30	-0.23	-0.19	0.28	0.02	-0.06	0.05

CHO=Carbohydrates; Femur Neck-ax=Femur neck axis; Femur troch.=Femur trochanter

Appendix 3.6: AIS-braced group correlations (r) between BMC and nutritional parameters

	24 hr. Recall Questionnaire							
	Energy Intake (kcals)	Weight (g)	CHO (%)	Fat (%)	Calcium (mg)	Sodium (mg)	Protein (%)	Vitamin D (IU)
Head	-0.51	-0.03	-0.28	0.02	-0.20	-0.23	0.09	-0.32
Arms	-0.30	0.34	-0.43	0.01	-0.31	0.06	-0.07	-0.33
Left arm	-0.34	0.30	-0.42	0.00	-0.31	0.01	-0.09	-0.38
Right arm	-0.26	0.36	-0.44	0.02	-0.31	0.11	-0.05	-0.27
Legs	-0.22	0.30	-0.35	0.13	-0.29	0.14	-0.06	-0.34
Left Leg	-0.23	0.28	-0.35	0.15	-0.29	0.13	-0.10	-0.34
Right leg	-0.22	0.32	-0.34	0.12	-0.29	0.15	-0.02	-0.33
Trunk	-0.38	0.10	-0.52	0.19	-0.35	0.03	-0.09	-0.38
Pelvis	-0.33	0.15	-0.42	0.20	-0.34	0.05	-0.17	-0.42
Femur neck axis	-0.14	0.22	-0.17	0.23	-0.16	0.09	-0.26	-0.45
Femur neck	-0.26	0.15	-0.22	0.23	-0.17	0.06	-0.13	-0.50
Femur shaft	-0.22	0.25	-0.28	0.04	-0.13	-0.05	-0.33	-0.51
Femur troch.	0.06	0.59	-0.37	0.11	-0.24	0.31	-0.18	-0.08
Femur wards	-0.30	0.15	-0.34	0.13	-0.30	0.02	-0.24	-0.57
Total femur	-0.10	0.43	-0.34	0.11	-0.20	0.15	-0.25	-0.33
Spine-L1	-0.22	0.43	-0.60	0.05	-0.38	0.17	-0.12	-0.22
Spine-L2	-0.32	0.38	-0.58	-0.02	-0.40	0.05	-0.10	-0.30
Spine-L3	-0.34	0.37	-0.55	-0.01	-0.45	0.03	-0.09	-0.22
Spine-L4	-0.23	0.36	-0.48	-0.03	-0.45	0.13	-0.10	0.00
Spine-L1-L4	-0.29	0.40	-0.56	-0.01	-0.44	0.10	-0.11	-0.18
Total spine	-0.31	0.30	-0.55	0.10	-0.40	0.11	-0.02	-0.29
Total body	-0.37	0.19	-0.45	0.13	-0.33	0.03	-0.06	-0.38

Appendix 3.7: AIS-not braced correlations (r) between BMC and nutritional parameters for

	24 hr. Recall Questionnaire							
	Energy Intake (kcals)	Weight (g)	CHO (%)	Fat (%)	Calcium (mg)	Sodium (mg)	Protein (%)	Vitamin D (IU)
Head	0.45	0.63	-0.19	0.34	-0.02	0.44	0.13	0.11
Arms	0.26	0.43	-0.25	0.16	-0.12	0.58	0.58	0.31
Left arm	0.28	0.48	-0.27	0.19	-0.09	0.64	0.63	0.33
Right arm	0.23	0.39	-0.22	0.13	-0.15	0.50	0.51	0.29
Legs	0.25	0.48	-0.27	0.10	-0.14	0.48	0.50	0.10
Left Leg	0.23	0.48	-0.27	0.10	-0.16	0.47	0.51	0.10
Right leg	0.27	0.47	-0.27	0.09	-0.11	0.49	0.49	0.09
Trunk	0.23	0.30	-0.10	0.25	0.04	0.33	0.30	-0.05
Pelvis	0.32	0.40	-0.12	0.25	0.04	0.39	0.25	-0.02
Femur neck axis	0.42	0.31	0.05	0.14	0.19	0.25	0.09	0.07
Femur neck	0.22	0.22	-0.11	0.10	0.13	0.17	0.16	0.01
Femur shaft	0.49	0.52	0.04	0.35	0.18	0.55	0.53	0.33
Femur troch.	0.18	0.37	-0.07	0.18	-0.07	0.25	0.35	0.07
Femur wards	0.18	0.09	-0.08	-0.14	0.18	0.09	0.06	-0.01
Total femur	0.37	0.47	-0.03	0.28	0.08	0.43	0.46	0.20
Spine-L1	0.59	0.54	0.02	0.14	0.16	0.67	0.46	0.25
Spine-L2	0.66	0.59	0.02	0.17	0.22	0.77	0.33	0.31
Spine-L3	0.58	0.55	0.04	0.35	0.11	0.62	0.47	0.36
Spine-L4	0.36	0.60	-0.26	0.11	-0.07	0.58	0.25	0.15
Spine-L1-L4	0.61	0.64	-0.06	0.23	0.10	0.74	0.42	0.30
Total spine	0.07	0.11	-0.15	0.23	0.02	0.21	0.33	-0.17
Total body	0.30	0.46	-0.21	0.22	-0.05	0.47	0.42	0.06

Appendix 3.8: Control group correlations (r) between BMC and Nutritional parameters

	24 hr. Recall Questionnaire							
	Energy Intake (Kcals)	Weight (g)	CHO (%)	Fat (%)	Calcium (mg)	Sodium (mg)	Protein (%)	Vitamin D (IU)
Head	-0.24	0.19	-0.25	-0.17	-0.26	0.28	0.23	-0.17
Arms	-0.14	-0.28	-0.11	0.02	-0.03	0.56	-0.03	0.03
Left arm	-0.17	-0.27	-0.13	0.00	-0.06	0.57	-0.02	-0.02
Right arm	-0.10	-0.29	-0.08	0.04	0.01	0.55	-0.05	0.08
Legs	-0.21	-0.02	-0.32	-0.16	-0.13	0.35	0.08	-0.07
Left Leg	-0.18	-0.06	-0.29	-0.13	-0.10	0.36	0.06	-0.05
Right leg	-0.23	0.01	-0.35	-0.19	-0.16	0.34	0.09	-0.09
Trunk	0.06	0.02	-0.14	-0.02	-0.07	0.58	0.07	-0.01
Pelvis	0.07	-0.04	-0.14	0.00	-0.05	0.62	0.03	0.05
Femur neck axis	0.01	0.23	-0.22	-0.13	-0.12	0.44	0.01	0.03
Femur neck	-0.01	0.10	-0.20	-0.09	-0.08	0.54	0.05	0.01
Femur shaft	0.03	0.17	-0.21	-0.07	-0.10	0.59	0.01	0.06
Femur trochanter	-0.08	0.16	-0.28	-0.12	-0.24	0.44	-0.01	0.14
Femur wards	-0.09	0.10	-0.24	-0.13	-0.16	0.55	0.28	-0.02
Total femur	-0.02	0.17	-0.25	-0.10	-0.17	0.55	0.01	0.09
Spine-L1	-0.01	0.35	-0.28	-0.13	-0.21	0.35	-0.18	-0.03
Spine-L2	-0.02	0.35	-0.31	-0.16	-0.27	0.36	-0.16	0.02
Spine-L3	-0.08	0.42	-0.35	-0.20	-0.28	0.29	-0.09	-0.12
Spine-L4	-0.24	0.47	-0.41	-0.23	-0.31	0.12	-0.16	-0.40
L1-L4	-0.09	0.41	-0.35	-0.19	-0.28	0.29	-0.15	-0.13
Total spine	0.13	0.20	-0.12	0.03	-0.07	0.50	0.03	-0.03
Total body	-0.12	0.01	-0.26	-0.11	-0.14	0.53	0.11	-0.06

CHO=carbohydrates

Appendix 3.9: AIS-Braced group correlations (r) between BMC and physical activity

	Godin-shephard LTEQ (times/wk)			IPAQ (METS)				LPAQ (intensity/hrs/wk)			
	Mild	Mod	Stren.	Mod.	Vig.	Walk	Total	1	2	3	4
Head	0.44	0.17	-0.14	-0.06	0.11	-0.06	-0.02	0.13	-0.04	0.39	-0.49
Arms	0.50	0.01	0.13	-0.14	0.03	-0.10	-0.11	0.15	-0.06	0.27	-0.28
Left arm	0.49	-0.01	0.09	-0.19	-0.02	-0.13	-0.17	0.13	-0.08	0.27	-0.29
Right arm	0.52	0.03	0.16	-0.09	0.07	-0.06	-0.05	0.17	-0.03	0.27	-0.27
Legs	0.42	-0.10	0.03	-0.17	-0.05	-0.11	-0.15	0.09	0.00	0.33	-0.27
Left Leg	0.44	-0.07	0.02	-0.18	-0.06	-0.14	-0.18	0.12	-0.01	0.36	-0.26
Right leg	0.40	-0.13	0.03	-0.15	-0.03	-0.07	-0.13	0.06	0.00	0.29	-0.28
Trunk	0.32	-0.06	0.11	-0.11	0.20	-0.12	-0.04	0.25	0.18	0.33	-0.31
Pelvis	0.40	-0.08	0.09	-0.17	0.00	-0.18	-0.16	0.04	0.17	0.29	-0.21
Femur neck axis	0.52	-0.13	-0.01	-0.41	-0.25	-0.29	-0.43	0.11	0.05	0.22	0.00
Femur neck	0.55	-0.09	-0.01	-0.35	-0.13	-0.23	-0.33	0.19	0.09	0.29	-0.12
Femur shaft	0.55	-0.04	0.00	-0.60	-0.21	-0.40	-0.56	0.36	-0.22	0.13	-0.04
Femur trochanter	0.48	-0.13	-0.04	-0.22	-0.17	-0.23	-0.27	-0.02	-0.04	0.14	-0.08
Femur wards	0.42	-0.03	-0.01	-0.31	-0.17	-0.22	-0.32	0.08	0.06	0.40	-0.10
Total femur	0.57	-0.10	-0.02	-0.42	-0.20	-0.32	-0.43	0.17	-0.10	0.17	-0.07
Spine-L1	0.44	0.17	-0.14	-0.06	0.11	-0.06	-0.02	0.13	-0.04	0.39	-0.49
Spine-L2	0.50	0.01	0.13	-0.14	0.03	-0.10	-0.11	0.15	-0.06	0.27	-0.28
Spine-L3	0.49	-0.01	0.09	-0.19	-0.02	-0.13	-0.17	0.13	-0.08	0.27	-0.29
Spine-L4	0.52	0.03	0.16	-0.09	0.07	-0.06	-0.05	0.17	-0.03	0.27	-0.27
Spine-L1-L4	0.42	-0.10	0.03	-0.17	-0.05	-0.11	-0.15	0.09	0.00	0.33	-0.27
Total spine	0.44	-0.07	0.02	-0.18	-0.06	-0.14	-0.18	0.12	-0.01	0.36	-0.26
Total body	0.40	-0.13	0.03	-0.15	-0.03	-0.07	-0.13	0.06	0.00	0.29	-0.28

Appendix 3.10: AIS-not braced group correlations (r) between BMC and physical activity

	Godin-shephard (times/wk)			IPAQ (METS)				LPAQ (intensity-hrs/wk)			
	Mild	Mod	Stren.	Mod.	Vig.	Walk	Total	1	2	3	4
Head	0.15	0.08	0.39	-0.18	-0.06	-0.14	-0.15	0.40	-0.36	0.18	0.15
Arms	0.17	0.04	0.31	-0.39	-0.41	-0.28	-0.40	0.29	-0.31	0.26	0.17
Left arm	0.12	-0.03	0.32	-0.44	-0.42	-0.28	-0.42	0.26	-0.29	0.24	0.12
Right arm	0.23	0.11	0.30	-0.34	-0.40	-0.28	-0.38	0.33	-0.32	0.28	0.23
Legs	0.29	-0.07	0.15	-0.35	-0.43	-0.21	-0.36	0.26	-0.16	0.21	0.29
Left Leg	0.32	-0.03	0.15	-0.35	-0.44	-0.22	-0.36	0.27	-0.16	0.21	0.32
Right leg	0.26	-0.10	0.15	-0.34	-0.43	-0.21	-0.35	0.25	-0.16	0.21	0.26
Trunk	0.41	0.12	0.16	-0.11	-0.06	0.05	-0.04	0.66	-0.03	0.41	0.41
Pelvis	0.35	0.11	0.24	-0.18	-0.09	0.00	-0.10	0.65	-0.13	0.39	0.35
Femur neck axis	0.14	-0.16	0.25	-0.19	-0.50	-0.15	-0.28	-0.09	-0.10	0.07	0.14
Femur neck	0.62	0.57	0.37	0.51	0.07	0.61	0.33	0.76	0.71	0.80	0.62
Femur shaft	15.00	15.00	15.00	14.00	14.00	14.00	14.00	15.00	15.00	15.00	15.00
Femur trochanter	0.23	-0.19	0.16	-0.19	-0.42	-0.18	-0.28	-0.01	-0.08	0.14	0.23
Femur wards	0.08	-0.16	0.31	-0.32	-0.26	-0.01	-0.20	0.07	0.10	0.14	0.08
Total femur	0.29	-0.01	0.11	-0.14	0.13	0.27	0.11	0.25	0.29	0.19	0.29
Spine-L1	0.01	-0.31	-0.05	-0.15	-0.41	-0.15	-0.24	-0.15	0.05	0.12	0.01
Spine-L2	0.22	-0.12	0.24	-0.26	-0.15	0.08	-0.10	0.15	0.17	0.19	0.22
Spine-L3	-0.13	-0.27	0.22	-0.39	-0.30	-0.18	-0.32	0.18	-0.22	0.15	-0.13
Spine-L4	-0.19	-0.24	0.35	-0.38	-0.28	-0.18	-0.31	0.24	-0.34	0.10	-0.19
Spine-L1-L4	-0.14	-0.01	0.37	-0.40	-0.44	-0.28	-0.41	0.09	-0.28	0.17	-0.14
Total spine	0.08	-0.18	0.25	0.01	-0.02	-0.02	-0.01	0.18	-0.27	-0.11	0.08
Total body	-0.10	-0.18	0.34	-0.31	-0.29	-0.18	-0.29	0.19	-0.31	0.08	-0.10

Appendix 3.11: Control group correlations (r) between BMC and physical activity

	Godin-shephard (times/wk)			IPAQ (METS)				LPAQ (intensity-hrs/wk)			
	Mild	Mod	Stren.	Mod.	Vig.	Walk	Total	1	2	3	4
Head	0.42	0.40	-0.26	-0.31	-0.11	-0.46	-0.44	-0.27	0.26	0.24	0.19
Arms	-0.08	-0.08	0.30	-0.23	0.23	0.17	-0.01	-0.26	-0.20	0.09	0.44
Left arm	-0.09	-0.07	0.28	-0.20	0.21	0.17	0.00	-0.29	-0.18	0.15	0.37
Right arm	-0.07	-0.08	0.31	-0.26	0.25	0.16	-0.03	-0.23	-0.22	0.02	0.50
Legs	-0.13	-0.23	0.42	-0.26	0.14	0.28	-0.03	-0.48	-0.29	0.05	0.58
Left Leg	-0.13	-0.22	0.39	-0.30	0.10	0.23	-0.09	-0.48	-0.28	0.07	0.58
Right leg	-0.14	-0.23	0.45	-0.22	0.19	0.32	0.03	-0.48	-0.30	0.04	0.57
Trunk	0.32	0.07	0.04	-0.32	-0.28	-0.12	-0.39	-0.29	-0.10	0.22	0.14
Pelvis	0.15	-0.08	0.18	-0.36	-0.22	0.06	-0.33	-0.32	-0.22	0.25	0.21
Femur neck axis	0.00	-0.23	0.45	-0.37	-0.24	0.26	-0.28	-0.37	-0.27	-0.03	0.30
Femur neck	-0.09	-0.30	0.45	-0.34	-0.21	0.26	-0.24	-0.40	-0.37	0.04	0.33
Femur shaft	0.09	-0.15	0.54	-0.24	-0.18	0.37	-0.12	-0.35	-0.24	0.15	0.27
Femur troch.	0.11	-0.05	0.37	-0.43	0.11	0.40	-0.13	-0.37	0.02	0.31	0.20
Femur wards	-0.01	-0.24	0.26	-0.26	-0.08	0.16	-0.17	-0.37	-0.33	-0.01	0.35
Total femur	0.08	-0.14	0.49	-0.36	-0.06	0.39	-0.15	-0.39	-0.15	0.21	0.26
L1	0.64	0.46	0.24	-0.24	-0.12	0.04	-0.22	-0.24	0.31	0.29	0.04
L2	0.60	0.41	0.22	-0.29	-0.09	0.09	-0.22	-0.26	0.32	0.39	-0.01
L3	0.63	0.46	0.17	-0.26	-0.05	0.00	-0.21	-0.19	0.30	0.25	0.08
L4	0.70	0.62	0.08	-0.18	0.05	-0.09	-0.15	-0.14	0.45	0.21	0.02
L1-L4	0.67	0.51	0.19	-0.26	-0.05	0.01	-0.21	-0.22	0.36	0.30	0.04
Total spine	0.42	0.40	-0.26	-0.31	-0.11	-0.46	-0.44	-0.27	0.26	0.24	0.19
Total body	-0.08	-0.08	0.30	-0.23	0.23	0.17	-0.01	-0.26	-0.20	0.09	0.44

Appendix 3.12: AIS-Braced group correlations (r) between BMC and anthropometrics

	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m^2)	AAM (yrs)	TBF (%)	TBM (g)	TFM (g)	TLM (g)
Head	0.60	0.55	0.58	0.39	0.22	0.22	0.74	0.50	0.55
Arms	0.18	0.78	0.81	0.58	-0.14	0.35	0.96	0.66	0.78
Left arm	0.16	0.76	0.83	0.62	-0.10	0.36	0.97	0.67	0.80
Right arm	0.20	0.80	0.78	0.54	-0.19	0.34	0.95	0.63	0.75
Legs	0.03	0.80	0.84	0.61	-0.15	0.42	0.95	0.70	0.77
Left Leg	0.06	0.78	0.85	0.63	-0.13	0.45	0.96	0.72	0.76
Right leg	0.00	0.82	0.82	0.58	-0.16	0.39	0.94	0.67	0.77
Trunk	0.31	0.72	0.90	0.75	-0.09	0.58	0.96	0.82	0.77
Pelvis	0.12	0.71	0.87	0.71	-0.12	0.52	0.96	0.77	0.75
Femur neck axis	-0.36	0.48	0.53	0.41	-0.34	0.24	0.66	0.41	0.49
Femur neck	-0.18	0.63	0.67	0.51	-0.26	0.30	0.82	0.54	0.64
Femur shaft	-0.16	0.41	0.62	0.58	-0.12	0.27	0.74	0.50	0.62
Femur trochanter	-0.15	0.68	0.59	0.35	0.04	0.19	0.77	0.43	0.61
Femur wards	-0.25	0.61	0.73	0.60	-0.22	0.36	0.77	0.59	0.68
Total femur	-0.17	0.62	0.67	0.51	-0.07	0.26	0.84	0.52	0.68
L1	0.13	0.79	0.79	0.55	-0.06	0.34	0.92	0.62	0.78
L2	0.12	0.78	0.82	0.60	0.08	0.31	0.91	0.63	0.84
L3	0.10	0.83	0.79	0.54	0.05	0.29	0.86	0.60	0.82
L4	0.17	0.87	0.80	0.52	0.08	0.34	0.85	0.63	0.81
L1-L4	0.14	0.85	0.83	0.57	0.04	0.33	0.91	0.64	0.84
Total spine	0.06	0.85	0.82	0.58	-0.08	0.38	0.87	0.66	0.80
Total body	0.27	0.79	0.89	0.68	-0.07	0.48	1.00	0.77	0.80

BMI=body mass index; AAM=age at menerache; TBF=total body fat; TBM=total body mass;
TFM=total fat mass; TLM=total lean mass

Appendix 3.13: AIS-not braced group correlation(s) between BMC and anthropometrics

	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m2)	AAM (yrs)	TBF (%)	TBM (g)	TFM (g)	TLM (g)
Head	0.61	0.46	0.59	0.39	-0.10	-0.07	0.74	0.21	0.74
Arms	0.36	0.69	0.48	0.14	0.26	-0.14	0.87	0.13	0.68
Left arm	0.35	0.75	0.49	0.12	0.26	-0.14	0.87	0.12	0.71
Right arm	0.35	0.62	0.46	0.15	0.26	-0.13	0.86	0.13	0.64
Legs	0.30	0.76	0.69	0.34	0.20	0.13	0.92	0.36	0.68
Left Leg	0.30	0.76	0.69	0.34	0.17	0.15	0.92	0.37	0.66
Right leg	0.30	0.77	0.69	0.34	0.21	0.12	0.93	0.35	0.70
Trunk	0.44	0.44	0.74	0.58	0.08	0.46	0.93	0.66	0.34
Pelvis	0.48	0.46	0.76	0.59	0.11	0.35	0.94	0.59	0.47
Femur neck axis	-0.01	0.43	0.45	0.26	0.57	0.07	0.60	0.21	0.45
Femur neck	0.12	0.45	0.54	0.36	0.36	0.18	0.64	0.32	0.45
Femur shaft	0.29	0.73	0.44	0.07	0.37	0.00	0.83	0.16	0.52
Femur trochanter	0.36	0.55	0.42	0.16	0.05	0.22	0.67	0.29	0.27
Femur wards	-0.07	0.35	0.39	0.24	0.50	0.10	0.41	0.18	0.39
Total femur	0.33	0.70	0.51	0.17	0.26	0.13	0.84	0.27	0.47
L1	0.39	0.72	0.45	0.09	0.37	-0.18	0.84	0.07	0.75
L2	0.26	0.61	0.42	0.12	0.36	-0.26	0.69	0.02	0.76
L3	0.36	0.61	0.29	-0.03	0.43	-0.28	0.75	-0.06	0.63
L4	0.31	0.58	0.48	0.21	-0.21	-0.19	0.58	0.05	0.78
L1-L4	0.37	0.71	0.46	0.11	0.25	-0.26	0.80	0.02	0.82
Total spine	0.48	0.31	0.64	0.54	0.05	0.50	0.84	0.65	0.19
Total body	0.45	0.64	0.76	0.48	0.13	0.25	1.00	0.50	0.60

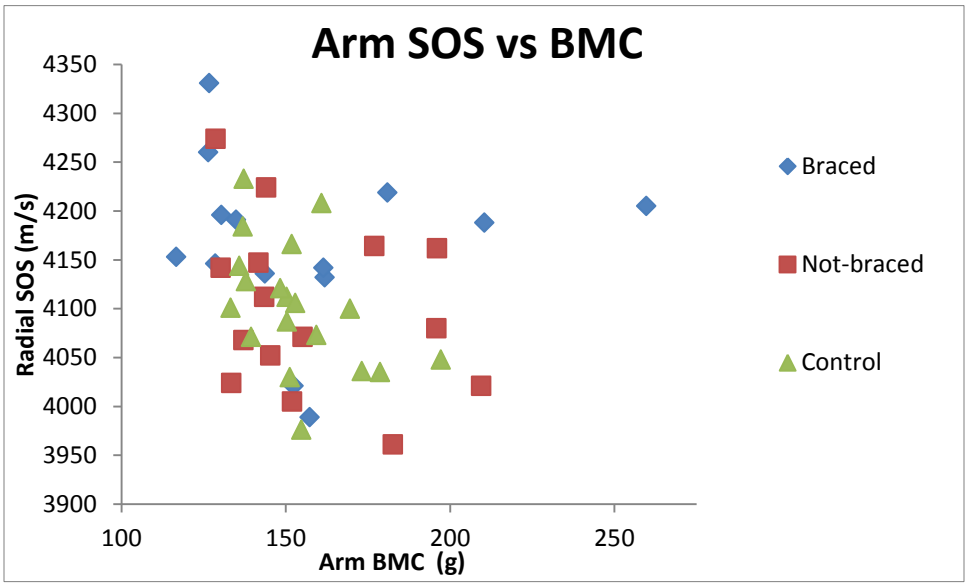
BMI=body mass index; AAM=age at menerache; TBF=total body fat; TBM=total body mass;
TFM=total fat mass; TLM=total lean mass

Appendix 3.14: Control group correlations (r) between BMC and anthropometrics

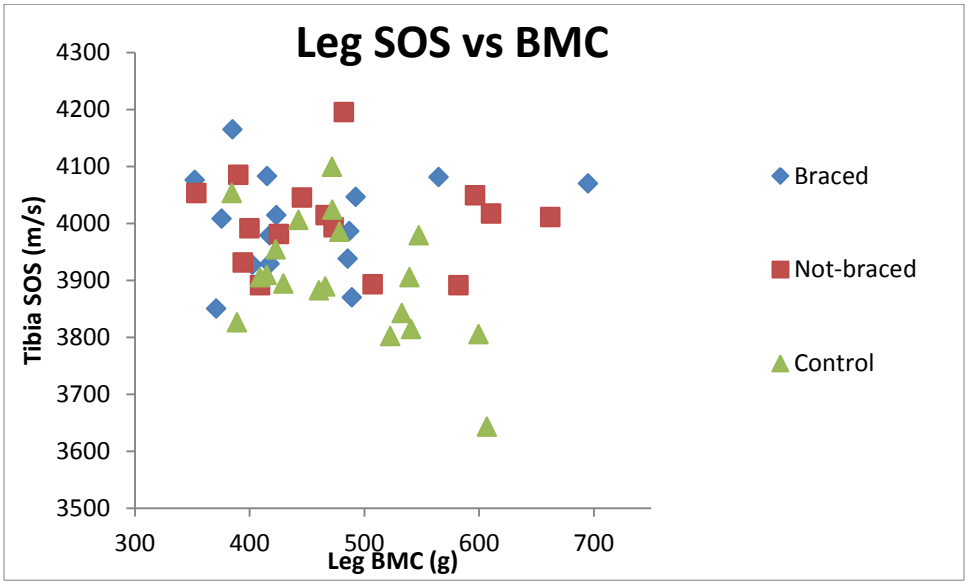
	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m2)	AAM (yrs)	TBF (%)	TBM (g)	TFM (g)	TLM (g)
Head	0.04	-0.03	0.31	0.40	0.23	0.32	0.56	0.34	0.04
Arms	-0.14	0.48	0.68	0.54	0.14	0.20	0.83	0.41	-0.14
Left arm	-0.14	0.43	0.66	0.55	0.16	0.19	0.81	0.39	-0.14
Right arm	-0.15	0.51	0.68	0.52	0.12	0.20	0.84	0.41	-0.15
Legs	-0.23	0.73	0.82	0.56	0.12	0.26	0.85	0.53	-0.23
Left Leg	-0.25	0.73	0.82	0.57	0.13	0.29	0.86	0.55	-0.25
Right leg	-0.22	0.73	0.81	0.56	0.12	0.23	0.82	0.50	-0.22
Trunk	0.16	0.46	0.71	0.59	0.08	0.48	0.93	0.62	0.16
Pelvis	0.00	0.46	0.70	0.57	-0.06	0.31	0.92	0.50	0.00
Femur neck axis	-0.31	0.62	0.49	0.23	-0.08	0.01	0.71	0.21	-0.31
Femur neck	-0.26	0.68	0.56	0.29	-0.03	0.05	0.79	0.27	-0.26
Femur shaft	-0.27	0.61	0.51	0.26	0.08	-0.05	0.79	0.18	-0.27
Femur trochanter	-0.31	0.32	0.38	0.29	-0.19	-0.17	0.59	0.03	-0.31
Femur wards	-0.17	0.44	0.55	0.42	-0.04	0.15	0.76	0.32	-0.17
Total femur	-0.31	0.54	0.50	0.30	-0.05	-0.09	0.76	0.14	-0.31
L1	0.16	0.47	0.29	0.05	0.31	0.05	0.60	0.16	0.16
L2	0.09	0.38	0.24	0.05	0.17	-0.06	0.60	0.05	0.09
L3	0.19	0.42	0.24	0.02	0.40	-0.02	0.60	0.09	0.19
L4	0.38	0.43	0.24	0.01	0.45	0.02	0.52	0.11	0.38
L1-L4	0.21	0.44	0.26	0.03	0.34	-0.01	0.60	0.10	0.21
Total spine	0.37	0.44	0.55	0.39	0.27	0.51	0.77	0.57	0.37
Total body	-0.03	0.57	0.82	0.66	0.14	0.43	1.00	0.63	-0.03

BMI=body mass index; AAM=age at menerache; TBF=total body fat; TBM=total body mass;
TFM=total fat mass; TLM=total lean mass

Appendix 3.15: Scatter plot between peripheral radial SOS and peripheral right arm BMC



Appendix 3.16: Scatter plot between peripheral tibial SOS and peripheral right leg BMC



Appendix 3.17: Skewness and kurtosis for anthropometrics

Anthropometrics			
	Mean±SD	**Skewness**	**Kurtosis**
Age (yrs)	1. 25.56 ±5.77 2. 24.00±4.01 3. 24.30 ±5.20	1. 0.57 2. 0.73 3. 1.70	1. -1.37 2. -1.47 3. 3.04
Height (cm)	1. 167.26±7.95 2. 167.10±7.23 3. 166.40±5.81	1. 0.23 2. 1.37 3. 0.32	1. -0.66 2. 1.80 3. -0.28
Weight (kg)	1. 63.09±13.17 2. 64.54±10.22 3. 64.80±8.94	1. 1.58 2. 0.33 3. 0.22	1. 2.61 2. 0.81 3. -1.34
BMI (kg/m^2)	1. 22.41±3.30 2. 23.10±3.34 3. 23.20±2.57	1. 1.23 2. 1.27 3. 0.46	1. 0.70 2. 2.34 3. 6.59
AAM (yrs)	1. 13.12±1.66 2. 12.96±1.96 3. 12.92±1.38	1. 2.23 2. 1.13 3. -0.74	1. 6.86 2. 1.30 3. 0.31
TBF (%)	1. 30.41±6.78 2. 30.76±8.47 3. 33.11±7.46	1. 0.66 2. 0.43 3. -0.18	1. 0.27 2. 1.22 3. -0.76
TBM (g)	1. 2543.15±522.48 2. 2662.72±502.11 3. 2647.47±317.13	1. 1.76 2. 0.87 3. 0.51	1. 3.64 2. -.030 3. -0.64
TFM (g)	1. 18748.84±8233.98 2. 19144.77±8023.69 3. 20564.68±6797.87	1. 1.93 2. 1.64 3. 0.34	1. 4.18 2. 4.48 3. -1.29
TLM (g)	1. 41089.08±5722.28 2. 41619.13±5521.77 3. 40428.74±4322.11	1. 0.12 2. 0.80 3. -0.21	1. -0.92 2. 1.67 3. 0.71

1=AIS braced, 2=AIS-Not braced, 3=Healthy control
AAM=Age at menerache; TBF= Total body fat; TBM=Total bone mass; TFM=total fat mass; TLM=Total lean mass

Appendix 3.18: Skewness and kurtosis for physical activity parameters

Physical Activity				
		Mean±SD	**Skewness**	**Kurtosis**
Godin-Shephard LTEQ(times/wk)	**Mild exercise**	1. 2.60 ±1.72 2. 3.2±2.6 3. 4.63±3.56	1. 0.05 2. 0.58 3. 1.20	1. -1.13 2. -0.78 3. 1.88
	Moderate exercise	1. 2.10±1.96 2. 3.00±2.11 3. 3.32±2.52	1. 0.36 2. 0.28 3. 2.02	1. -1.37 2. -.70 3. 5.60
	Strenuous exercise	1. 2.20±1.93 2. 1.90±1.91 3. 2.89±1.76	1. 0.62 2. 0.74 3. -0.31	1. -1.16 2. -0.40 3. -0.58
IPAQ (mets)	**Moderate**	1. 2780.00±4182.34 2. 2.51.70±2051.39 3. 916.10±1816.81	1. 1.62 2. 0.84 3. 2.07	1. 1.35 2. -0.14 3. 2.93
	Vigorous	1. 2518.56±3962.88 2. 2653.78±3589.81 3. 1576.72±1435.98	1. 2.0 2. 2.30 3. 0.83	1. 2.87 2. 6.34 3. 0.03
	Walking	1. 3914.67±7844.67 2. 2353.22±2996.90 3. 2054±2860.86	1. 2.68 2. 1.80 3. 2.11	1. 7.32 2. 2.87 3. 5.59
	Total	1. 9210.23±12692.33 2. 7058.70±7577.84 3. 4547.03±4063.78	1. 1.47 2. 1.87 3. 1.25	1. 0.48 2. 3.31 3. 0.60
LPAQ (hrs/wk)	**Intensity 1**	1. 0.27±0.27 2. 0.60±1.54 3. 1.07±0.14	1. 1.95 2. 3.38 3. 3.00	1. 2.74 2. 12.01 3. 10.01
	Intensity 2	1. 1.12±1.66 2. 1.25±3.07 3. 1.03±1.53	1. 1.87 2. 3.69 3. 3.67	1. 2.66 2. 13.9 3. 14.86
	Intensity 3	1. 1.48±1.62 2. 3.26±2.68 3. 2.91±4.75	1. 0.61 2. 0.48 3. 2.29	1. -1.45 2. -0.24 3. 5.21
	Intensity 4	1. 3.82±5.25 2. 6.00±6.0 3. 5.26±7.77	1. 1.68 2. 1.89 3. 1.09	1. 2.67 2. 2.95 3. -0.03

1=AIS braced, 2=AIS-Not braced, 3=Healthy control
LTEQ=Leisure-time exercise questionnaire; IPAQ=international physical activity questionnaire; LPAQ=Life-time activity questionnaire

Appendix 3.19: Skewness and kurtosis for nutritional parameters

	Nutritional Parameters			
		Mean	Skewness	Kurtosis
24-hr recall Questionnaire	Energy Intake (kcals)	1. 1831.66±0.35 2. 2557.40±1186.14 3. 1899.17±531.40	1. 0.77 2. 2.06 3. 1.56	1. -0.09 2. 6.10 3. 2.82
	Weight (g)	1. 3218.93±3952.32 2. 2776.15±873.31 3. 1898.10±667.62	1. 3.60 2. 1.16 3. 0.32	1. 13.45 2. 1.00 3. 0.66
	Protein (%)	1. 0.03±0.02 2. 0.38±0.01 3. 0.05±0.04	1. 0.36 2. 0.84 3. 3.52	1. -0.85 2. 0.85 3. 14.00
	Carbohydrate (%)	1. 0.10±0.05 2. 0.11±0.06 3. 0.16±0.17	1. 0.86 2. 0.58 3. 4.05	1. -0.34 2. -0.45 3. 17.38
	Fat (%)	1. 0.03±0.01 2. 0.03±0.02 3. 0.04±0.04	1. 0.71 2. 0.93 3. 3.56	1. -0.01 2. -0.07 3. 0.14
	Sodium (mg)	1. 2966.33±1888.06 2. 2666.01±1241.67 3. 3068.94±1215.68	1. 0.85 2. -0.32 3. 0.41	1. 0.90 2. -0.86 3. -0.20
	Calcium (mg)	1. 1084.11±637.83 2. 1169.15±863.43 3. 1085.58±621.90	1. 1.41 2. 1.79 3. 0.53	1. 2.31 2. 3.08 3. -0.73
	Vitamin D (IU)	1. 180.90±145.89 2. 194.17±269.17 3. 149.85±149.65	1. 1.23 2. 2.64 3. 2.16	1. 0.32 2. 7.45 3. 5.70

1=AIS braced, 2=AIS-Not braced, 3=Healthy control

Appendix 3.20: Skewness and kurtosis for BMD values

	BMD		
	Mean±SD	**Skewness**	**Kurtosis**
Head	1. 2.26 ±0.29 2. 2.26 ±0.26 3. 2.29 ±0.24	1. 1.34 2. 0.26 3. 0.58	1. 4.26 2. -0.39 3. -0.37
Arms	1. 0.84 ±0.12 2. 0.85 ±0.09 3. 0.83 ±0.04	1. 2.48 2. 2.82 3. 0.48	1. 7.64 2. 9.37 3. -0.82
Left arm	1. 0.82 ±0.12 2. 0.84±0.09 3. 0.82 ±0.04	1. 2.41 2. 2.78 3. 0.11	1. 7.54 2. 0.36 3. -1.06
Right arm	1. 0.85±0.12 2. 0.86±0.10 3. *0.84 ±0.04*	1. -0.06 2. 0.38 3. 0.36	1. -0.67 2. -0.38 3. 0.19
Legs	1. 0.21 ±0.10 2. 1.27±0.11 3. 1.26±0.11	1. 2.46 2. 2.72 3. 0.76	1. 7.41 2. 8.76 3. 0.25
Left Leg	1. 1.21 ±0.11 2. 1.26±0.11 3. *1.26 ±0.08*	1. 0.06 2. 0.18 3. 0.07	1. -1.04 2. -0.73 3. -0.01
Right leg	1. 1.22±0.10 2. 1.27±0.11 3. 1.26±0.08	1. 0.02 2. 0.26 3. 0.17	1. -0.91 2. -0.63 3. 0.36
Trunk	1. 0.91 ± 0.09 2. 0.92±0.09 3. 0.93±0.05	1. 1.22 2. 0.58 3. 0.50	1. 1.01 2. 0.88 3. 0.38
Pelvis	1. 1.13 ±0.11 2. 1.14±0.12 3. 1.17±0.09	1. 0.27 2. -0.15 3. 1.24	1. -0.38 2. -0.75 3. 1.80
Femur neck axis	1. 0.92 ±0.12 2. 0.96±0.10 3. 1.02±-.13	1. -0.32 2. -0.67 3. -0.04	1. 0.15 2. 0.64 3. -0.81

BMD			
	Mean±SD	**Skewness**	**Kurtosis**
Femur neck	1. 1.00±0.1 2. 1.02±0.09 3. 1.08±0.10	1. -0.11 2. -0.78 3. -0.04	1. -0.25 2. 0.93 3. -0.92
Femur shaft	1. 16.36±1.97 2. 16.88±1.84	1. -0.96 2. 0.95 3. 1.12	1. 0.86 2. 0.45 3. 1.87
Femur trochanter	1. 0.72±0.09 2. 0.78±0.09 3. 0.80±0.11	1. -0.08 2. 0.75 3. 0.41	1. -0.85 2. 0.10 3. 0.48
Femur wards	1. 0.91 ±0.12 2. 0.93±0.11 3. 1.00±0.15	1. -0.08 2. 0.74 3. 0.43	1. -0.75 2. 0.01 3. -0.44
Total femur	1. 0.97±0.10 2. 1.02±0.08 3. 1.05±0.11	1. -0.88 2. 0.24 3. 0.46	1. 0.27 2. -1.12 3. -0.28
Spine-L1	1. 1.10±0.13 2. 1.14±0.14 3. 1.15±0.12	4. 1.64 5. 0.75 6. -0.04	1. 2.85 2. 0.68 3. -0.37
Spine-L2	1. 1.17 ± 0.13 2. 1.23±0.11 3. 1.24±0.13	1. 1.60 2. 0.81 3. -0.04	1. 2.58 2. 0.55 3. -0.37
Spine-L3	1. 1.25 ±0.13 2. 1.23±0.08 3. 1.27±0.12	1. 1.32 2. 0.59 3. -0.02	1. 2.46 2. -0.08 3. -0.00
Spine-L4	1. 1.17± 014 2. 1.18±0.12 3. 1.22±0.11	1. 0.34 2. 0.98 3. 0.40	1. 0.41 2. 1.52 3. -0.99
Spine-L1-L4	1. 1.17 ± 0.13 2. 1.19±0.09 3. 1.22±0.11	1. 1.41 2. 0.48 3. 0.09	1. 2.78 2. -0.24 3. -0.92
Total spine	1. 0.98 ±0.13 2. 1.02±0.14 3. 1.07±0.09	1. 2.56 2. 1.13 3. -0.54	1. 6.57 2. 2.74 3. 0.28
Total body	1. 1.13 ±0.09 2. 1.15±0.8 3. 1.15±0.06	1. 1.70 2. 0.19 3. 0.11	1. 3.95 2. 0.08 3. 0.17

Appendix 3:21: Skewness and kurtosis for BMC values

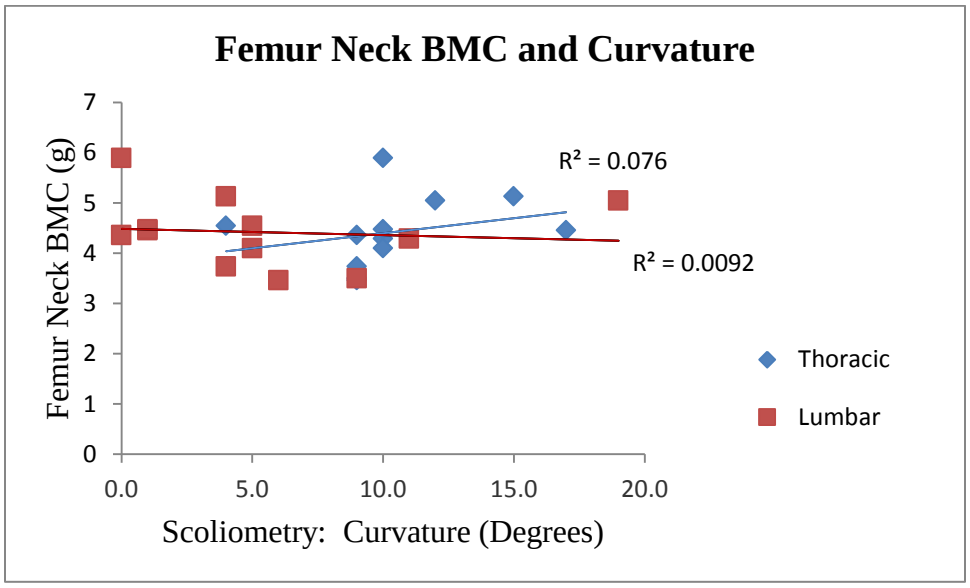
BMC			
	Mean±SD	**Skewness**	**Kurtosis**
Head	1. 487.79±79 2. 493.92±67.65 3. 488.43±65.80	1. 1.10 2. 0.01 3. 0.88	1. 3.90 2. -1.04 3. 1.71
Arms	1. 314.70±74.64 2. 324.44±53.64 3. 314.81±33.20	1. 1.67 2. 0.54 3. 1.06	1. 2.76 2. -1.13 3. 0.90
Left arm	1. 154.83±38.19 2. 157.75±27.30 3. 153.66±16.72	1. 1.76 2. 0.71 3. 1.07	1. 3.34 2. -0.89 3. 1.12
Right arm	1. 159.87±36.81 2. 166.69±26.81 3. 161.16±16.91	1. 1.53 2. 0.37 3. 0.95	1. 2.18 2. -1.12 3. 0.45
Legs	1. 911.40±174.06 2. 968.91±195.25 3. 963.70±134.93	1. 1.48 2. 0.64 3. 0.39	1. 2.50 2. -0.89 3. -0.76
Left Leg	1. 451.16±89.24 2. 479.27±9494.06 3. 480.68±67.23	1. 1.59 2. 0.65 3. 0.40	1. 3.00 2. -0.72 3. -0.79
Right leg	1. 460.24±85.28 2. 489.64±101.62 3. 483.02±68/29	1. 1.34 2. 0.64 3. 0.38	1. 1.92 2. -0.01 3. -0.70
Trunk	1. 29.26±232.91 2. 875.45±242.49 3. 888.38±156.78	1. 1.39 2. 1.59 3. 0.58	1. 1.66 2. 3.51 3. -1.02
Pelvis	1. 314.46±75.66 2. 347.36±98.76 3. 352.20±64.59	1. 1.52 2. 1.48 3. 0.80	1. 3.43 2. 2.76 3. -0.34
Femur neck axis	1. 2.05±0.32 2. 2.25±0.30 3. 2.36±0.34	1. 3.87 2. -0.17 3. 0.55	1. 15.00 2. -0.21 3. 0.25
Femur neck	1. 4.54±0.68 2. 4.89±0.61 3. 5.07±0.58	1. 0.13 2. -0.55 3. 0.53	1. 0.18 2. 0.67 3. 0.37
Femur shaft	1. 16.36±1.97 2. 16.88±1.84 3. 17.49±1.95	1. -0.36 2. 0.40 3. 0.99	1. 0.15 2. -0.38 3. 1.28
Femur trochanter	1. 8.29±2.41 2. 8.72±1.65 3. 8.69±1.85	1. 1.42 2. 0.43 3. 1.74	1. 1.49 2. 0.06 3. 6.50
Femur wards	1. 2.11±0.49 2. 2.37±0.52 3. 2.47±0.52	1. 0.00 2. 0.99 3. 0.73	1. 0.54 2. 2.35 3. -0.26
Total femur	1. 29.20±4.62 2. 30.49±3.60 3. 31.25±4.06	1. 0.76 2. 0.53 3. 1.53	1. 0.64 2. -0.32 3. 4.48

BMC			
	Mean±SD	**Skewness**	**Kurtosis**
Spine-L1	1. 14.72±2.88 2. 14.25±2.76 3. 13.60±2.24	1. 1.00 2. 0.96 3. 0.41	1. 0.18 2. 0.19 3. -0.52
Spine-L2	1. 15.56±2.92 2. 15.70±3.01 3. 15.87±2.74	1. 0.97 2. 1.28 3. 0.37	1. 0.80 2. 1.14 3. 0.22
Spine-L3	1. 18.31±3.63 2. 18.81±4.0 3. 18.04±2.96	1. 1.14 2. 0.75 3. -0.01	1. 1.61 2. -0.18 3. -0.76
Spine-L4	1. 19.73±4.06 2. 18.76±3.81 3. 19.94±2.64	1. 0.73 2. 0.09 3. 0.58	1. 0.15 2. -0.50 3. 0.01
Spine-L1-L4	1. 67.32±2.88 2. 67.53±12.03 3. 67.46±10.23	1. 1.09 2. 0.96 3. 0.26	1. 1.15 2. -0.66 3. -0.47
Total spine	1. 267.47±66.05 2. 263.84±59.99 3. 258.42±42.18	1. 0.70 2. 0.93 3. 0.01	1. -0.48 2. 1.141 3. -0.84
Total body	1. 2543.15±522.48 2. 2662.72±502.11 3. 2655.32±323.82	1. 1.76 2. 0.87 3. 0.43	1. 3.64 2. -0.31 3. -0.77

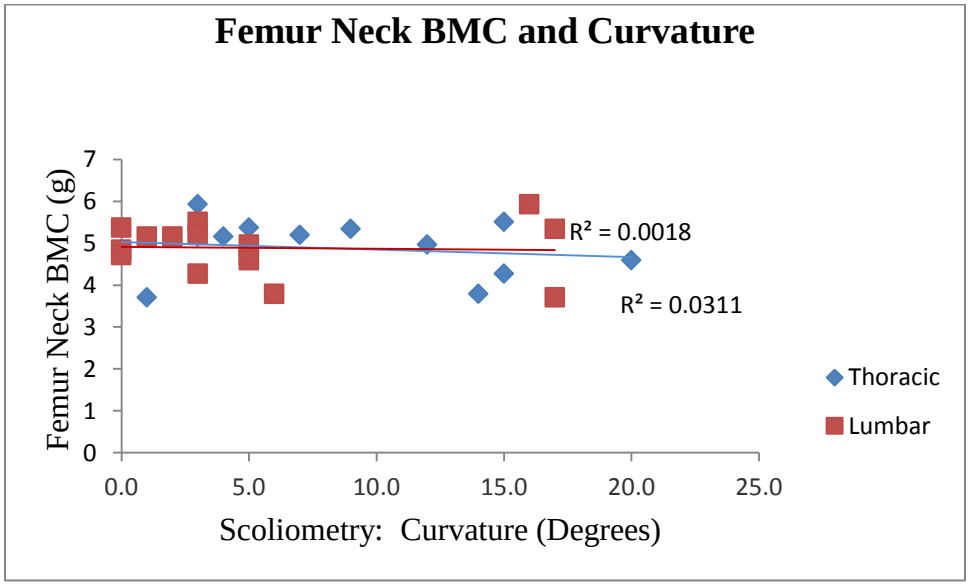
Appendix 3:22: Skewness and kurtosis for radial and tibial SOS

	SOS		
	Mean±SD	**Skewness**	**Kurtosis**
Non-dominant Radius	1. 4164.93±86.80 2. 4100.47±85.62 3. 4103.11±65.39	1. -0.38 2. 0.40 3. 0.30	1. 1.0 2. -0.25 3. -0.30
Non-dominant Tibia	1. 4001.47±87.81 2. 4002.67±81.70 3. 3907.53±107.35	1. -0.07 2. 0.53 3. -0.54	1. -0.52 2. 0.94 3. 0.81

Appendix 3.23: Scatterplots between femur neck BMC and curve angle using a scoliometer-AIS-Braced group



Appendix 3.24: Scatterplots between femur neck BMC and curve angle using a scoliometer-AIS-Not Braced group



Appendix 3.25: Scatterplots between femur neck BMC and curve angle using a scoliometer-Control group